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THE ENGINEERING SCHOOL AND THE ENGINEEER

Address of F. E. Turneaure, M. W. S. E., at the Annual Dinner of the Western Society of Engineers, Hotel Sherman, January 10, 1917.*

In casting about for a topic for this paper, it occurred to the writer that, in view of current discussions by engineers and educators of the question of engineering education, a brief outline of the development of the engineering school as related to the development of the engineering profession itself would be of interest.

Under present conditions, the profession is almost wholly dependent upon the engineering school for recruits to its ranks, and it is important that the training given by the school shall be as effective as possible. To secure the best results, there must be cordial co-operation between the school and the profession; between teacher and the engineer. On the one hand, the teacher must understand thoroughly the requirements of the profession, and on the other hand the engineer must recognize the limitations of school training.

It may be stated at the outset, as a fundamental proposition, that as a profession develops there comes a time when sufficient organized knowledge has been accumulated that it becomes profitable and desirable to teach some of this knowledge in schools. It is always possible to get this knowledge by self study and from practitioners themselves, but as the bulk of this information becomes large, and, especially, as it comes to be based upon laws and principles, it is found to be much more economical to get at least a part of it in a school. The school then becomes justified, and its curriculum will naturally be developed parallel with the development of organized knowledge in the particular profession in question. In the long run, the question as to what should be taught in such a school will be determined by answering the question whether or not it is more economical of time and results to learn any particular subject in school than it is in practice.

If we go back a little more than a hundred years, we find that there were no schools in existence for the training of engineers.

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There was, in fact, scarcely enough organized material to make it profitable to teach engineering in a school. During the past century a great evolution has taken place, both in the profession itself and in the schools which have been developed to give instruction in its now numerous branches. At the present time the amount of organized and scientific material available to the teacher is overwhelming, and the great problem which now confronts him is the selection of such material, and in so fixing the length of course as will, broadly considered, give the best results.

Engineering, considered as the art of construction, dates from ancient times, but as a profession based upon scientific knowledge, it is not much over a hundred years old. Previous to the development of the steam engine and the processes of iron production on a large scale, both occurring in the latter part of the eighteenth century, the work of the engineer was confined almost wholly to structures of earth work and masonry and to the art of mining. Beyond the work of the surveyor, engineering art was based almost entirely upon empirical rules of practice which had been collected and handed down from one generation to the next. There was practically no scientific knowledge then available, and such information as existed concerning the nature of materials rested on no secure foundation. But as an art, engineering was developed to a very considerable degree many centuries before our time. The pyramids of Egypt, the irrigation works of that country and of India, the highways, aqueducts and reservoirs of Rome and the walls of China are well-known examples of good engineering art. Many ingenious mechanisms were used in the execution of these great works, such as the block and tackle, the wedge and inclined plane, and the screw. Expert use of certain materials was early developed, such as lead, bronze, lime and puzzolana cement. A museum of bronze fittings from ancient Rome and Pompeii looks very much like a modern plumbing shop.

But while many great works were well constructed in ancient times, their design was not based to any considerable extent on scientific or rational principles. The principles of mechanics were as yet very slightly developed, and while the Romans understood the general behavior of the arch, their designs were based on practical rules rather than on rational analysis. Anyone who has observed their work closely must conclude that their factor of safety (or ignorance) was exceedingly high. Compared to the loads carried, their walls and piers were of immense thickness, and their permanent roads were veritable walls built in the ground. Strength and durability were secured by a lavish use of materials. One has often heard the massive construction of the ancient Romans compared to that of modern engineers to the detriment of the latter; but, as a matter of fact, if the modern engineer was as lavish in the use of materials as his Roman predecessor, there would be even more complaint than at present with the high cost of living.

We must, however, pay our highest respects to these ancient builders, as they had no scientific knowledge to guide them. In hydraulics, for example, it was not clearly understood at that time that the quantity of water flowing in a canal was the product of the cross-section by the velocity. In the distribution system of Rome, the water was measured by means of short tubes or orifices placed in the reservoir wall, but no adequate allowance was made for the varying length of pipes leading therefrom. The work of computation as carried on by the Romans was greatly handicapped by the notation employed. A good idea of this can be had from a book written by Frontinus, Water Works Commissioner of Rome, A. D. 97. Decimal fractions did not, of course, exist, and such a quantity as 3.632 had to be represented by a string of simple fractions like 3 plus 1/2 plus 1/12 plus 1/24 plus 2/288, a word being used for each fraction. Imagine yourself multiplying two such numbers, and you can appreciate our indebtedness to the Arabs. While the art of construction was thus on a purely empirical basis, there was one phase of the work of the engineer which was well developed by the ancients and placed upon a scientific foundation: this was the art of surveying. Very good work was done in those days in leveling and in mapping, although the instruments used were rather crude. This early development of the art of surveying may be accounted for by the interest of the ancients in the science of mathematics and astronomy, and from the fact that it did not rest upon an experimental basis. Before leaving this subject, mention should be made of two great writers of ancient times whose published works have come down to us: Vitruvius, who wrote a great treatise on architecture, and Archimedes, the inventor and mathematician, whose remarkable mathematical work was far head of his time and remained practically dormant for many centuries. But there could be no general dissemination of ideas along these lines, and experimental science was unknown. The time was far distant for the establishment of schools of engineering.

From the time of ancient Rome until about the eighteenth century, there was very little progress in construction, excepting in the development of Gothic architecture. Indeed, experience alone could hardly have carried the art of construction much farther; a scientific foundation was necessary for further progress. While experience is a necessary part of an engineer's equipment, experience without theory would never have given us much more than the Romans had already produced. China is an excellent example of a country with thousands of years of experience as a civilized nation, but without any theory, and its state of progress shows how poor a guide experience alone may be. Side by side in that country one may see fine examples of cut stone masonry in revetment walls and iron bulls placed along the bank of a river, both types of structures intended for the same purpose—to prevent the stream from flooding its banks. Not only was further progress dependent upon science, but the practical art of the engineer required also the stimu-

lus of the steam engine and the cheap production of iron to bring about a rapid growth, and this did not occur until about the beginning of the 19th century.

In the development of scientific principles, a good deal of thinking had, however, been going on during the preceding two or three centuries by a few great minds which prepared the way for the work of the inventors, scientists and engineers of the early part of the 19th century. At the very beginning of the 16th century that great artist, architect, mathematician and engineer, Leonardo da Vinci, made his wonderful studies in mechanics. This subject was taken up by others and gradually in the course of 300 years the behavior of gases and elastic solids was placed on a scientific basis. Leonardo was a military engineer in charge of fortresses under Cæsar Borgia of Italy. He was much more than this, however, and publications of his studies include sketches of subways, canal locks, draw bridges, sanitary stalls for cattle and all kinds of mechanical devices and even of flying machines, for Leonardo was a serious student of man flight. In the mechanics of materials his ideas were not at all accurate. From his sketches it appears that he considered that the strength of a beam was proportional to its cross section, and that of a column inversely proportional to its length. His knowledge of this subject was on a kind of qualitative basis; it did not rest upon a mathematical foundation.

Following Leonardo, the development of physical science became somewhat more rapid, although still very slow. How slow may be illustrated by the history of the theory of the strength of simple beams. Leonardo, as we have seen, proposed a solution which was wrong. The great Gallileo undertook to discuss this problem and published his ideas in 1638. Correct results, however, could not be reached until the discovery of Hook's laws, which was published by Robert Hook in 1678. Among others who later studied this problem were Mariotte of the French Academy and Bernoulli, in the latter part of the 17th century. Coulomb made some contributions in 1773 and Navier brought the subject nearly to completion in 1824; but it was not until 1857 that the publications of St. Venant, a student of Navier, placed the subject on its present rational basis. Thus we see how the theory of the strength of simple beams required over three hundred years for its development from the time of the studies of Leonardo.

During the period just described, the foundations were laid in physics and chemistry by such men as Newton, Mariotte and Coulomb; and in experimental hydraulics, Bernoulli had established many fundamental laws, so that at the beginning of the 19th century a very considerable body of knowledge was available to the engineer.

Most of the foregoing names are names of mathematicians, physicists and academicians, who confined their studies almost wholly to the scientific side of problems and made little use of their knowledge in the useful arts. Such studies were, however, absolutely fundamental to further progress in engineering, but progress

would have doubtless been much more rapid had there been as close co-operation between the scientist and the practical man as there is at the present time.

Let us now turn to an examination of the state of development of the work of the engineer during the time from Leonardo to the beginning of the 19th century. Leonardo was himself a military engineer, but few of the others that have been mentioned had any connection with practical work. Indeed, there was not much demand for anything beyond masonry and earthwork, as inventive genius had not yet produced the multiplication of power by the steam engine. The canal lock was invented about 1440, but it was not until 1642 that a summit level canal was built. The Languedoc canal, completed in 1681, was for over a century the longest and most important canal in the world. The corps of royal military engineers of France was organized by Henry IV. about the beginning of the 17th century. In England much the same conditions prevailed as in France, although canal construction came somewhat later. The first dock of which we have any record was built in London in 1660 and the first one in Liverpool in 1709. Progress was exceedingly slow up to 1800, and at that date the greatest industrial country of the world possessed but 180 miles of well-built highway and about 100 lighthouses. Engineering was still confined principally to works of a military character and the word "engineer" was still a military term.

Towards the end of the 18th century the demand for good roads, canals and other public works in England led very rapidly to the development of the new profession of civil engineering and produced such well-known men as Smeaton, Rennie, Telford, Tredgold and the two Stevensons. In 1803, Telford, who was afterwards the first president of the Institution of Civil Engineers, made a report to the Government on its highways, and was later given charge of the construction of a large system in Great Britain. The Hollyhead Road constructed by him was opened in 1826. This work included the suspension bridges at Conway and across the Menai Straits, which bridges are still standing and in a good state of repair. It may be pointed out, however, that the design of these bridges did not require the analysis of beams or trusses, the design of the stiffening trusses being a matter of judgment. Canal building developed in England very rapidly about this time and many of the most prominent engineers of that day received their early training in canal construction. Lighthouse construction was also an important field of work in Great Britain which developed almost wholly after 1800. All of this early work was accomplished with little scientific foundation and without the aid of engineering schools. Smeaton was a mathematical instrument maker and experimenter. Telford began life as a mason and learned the art of masonry construction by seven laborious years of apprenticeship. Tredgold began as a carpenter, but, recognizing his lack of knowledge of the principles of construction, spent a large amount of time

in study and experiment. He was one of the earliest scientific engineers, and his famous work on carpentry, published in 1820, was a very important scientific treatise. The principles of mechanics were, however, not yet fully developed, and Tredgold's explanations were in many cases incorrect. These engineers gained their knowledge from experience and from empirical rules collected and passed on from hand to hand. The engineer's notebook, in which were carefully recorded all such formulas, rules and other practical information gained from his own experience and the experience of others was invaluable and constituted, in most part, his library.

The limited field of engineering in the early part of the 19th century was indicated by a remark of Telford's to a young man who was considering going into civil engineering. Telford said: "I have made all the canals, all the roads and all the harbors. I do not see what there is that you propose to do." A broader and more scientific attitude was that of Tredgold, who made the following statement in connection with his famous definition of the term "civil engineering." He said: "The real extent to which it may be applied is limited only by the progress of science. Its scope and outlet will be increased with every discovery in philosophy and its resources with every invention in chemical and mechanical art, since its bounds are unlimited and nearly so must be the researches of its professors." This statement is worthy of the most far-seeing scientist of the present time.

The earliest work of an engineering nature in the United States was that of the surveyor, and the determination of state and national boundary lines, and the laying out of large tracts of land demanded the time of many men and was a matter of great importance, so that experts in this profession were rated highly in the community. Unlike the conditions in England, the early engineers in the United States were surveyors, or developed from surveyors, rather than from artisans, inventors and master builders. Thus we find that the first engineer mentioned in "Stuart's Lives of Engineers" is Major Andrew Ellicott, a man who devoted most of his life to the work of a surveyor. Ellicott was self-taught and, in addition to his work in surveying, he gave much attention to astronomy; and we find that, in his communications with the Secretary of the National Institute of France, he claims to have been at that time the only person in the United States interested in this subject, and deprecated the fact that there was no public way in which such studies could be encouraged. Ellicott made some reports on the subject of internal waterways, but had no part in any work of construction. He was primarily a surveyor and astronomer and in 1813 became professor of Mathematics at West Point.

The first engineer of construction in the United States of which we have record was Mr. James Geddes, Judge of Onondaga county, New York, and land surveyor. Judge Geddes early interested himself in the project of the Erie Canal, and was one of its active promoters. About the same time another county judge, Mr. Benjamin

Wright of Oneida County, became interested in the same project farther toward the East. Wright was also a surveyor and he, with Geddes, conducted the early surveys and made the first reports on this great project. It is reported that Judge Geddes had used the spirit level only once before he began his work on the Erie Canal, and it appears that at that time the dividing line between the surveyor and the engineer was determined by answering the question whether or not the person could use the engineer's level and run a profile. At the time these men began their work on the Erie Canal, there was no construction in this country of a similar character excepting some locks at Little Falls, N. Y., which had been built in 1792 by Mr. Weston, an English engineer, who had been brought to the United States for this purpose. It is reported that Weston was offered some years later a salary of $10,000 per year to take charge, as chief engineer, of the construction of the Erie Canal, but felt himself too old to undertake the task. As a matter of fact, the results of the work of Geddes and Wright in their early surveys and reports were so satisfactory that it was finally decided to place the work of construction in their hands. Ground was broken July 4, 1817, and the canal completed in 1825.

The success of the Erie Canal led very rapidly to many other canal projects and, as a matter of course, such engineers as Geddes and Wright were called upon for engineering advice in many of these projects. Some of the important ones were the Chesapeake and Ohio Canal, the Champlain Canal, the Welland Canal and the Illinois and Michigan Canal.

Following Geddes and Wright was quite a large group of engineers of a somewhat younger age who were employed as assistants under these two men and who received their early training on the Erie Canal. Among those mentioned by Stuart are three notable characters—Canvass White, David S. Bates and Nathan S. Roberts. White secured considerable school training at the Fairfield Academy, Oneida County, N. Y., where in 1813 he studied chemistry, mineralogy, mathematics, astronomy and surveying. He was employed by Wright as rodman in 1816, but before construction began he visited England, where he walked 2,000 miles in the examination of canal construction and other engineering work. He brought home with him maps and drawings and some new surveying instruments. He made a great contribution to the success of the Erie Canal in his discovery of the natural cement rock in New York state and introduced it on the canal masonry. He was later Chief Engineer of other canals and made a report on the water supply of New York City.

Messrs. Bates and Roberts were men very much like Geddes and Wright. They were interested in mathematics and surveying and were practical surveyors at the time the Erie Canal was begun. Bates was at first trained for the ministry, but preferred mathematics and surveying and the outdoor life. Roberts taught school and was principal of an academy at Whitesboro, N. Y. Both of these men

also served for a time as judges in their counties. Bates' practice included a report on water power at Niagara in 1831 and railroad reports for the state of Michigan in 1834. Roberts became chief engineer of the Erie Canal at the time of its enlargement in 1835, and reported on an aqueduct for Rochester and an improvement at Muscels Shoals.

Following these early engineers, who were primarily canal men, were men equally notable in railroad construction. The first railroad constructed in the United States was a short industrial road four miles long at Quincy, Massachusetts, built in 1826, to carry stone from the granite quarries to the docks, and primarily to furnish stone for the Bunker Hill monument. This road was promoted and constructed by Mr. Gridley Bryant. Bryant was an inventor and builder rather than a surveyor or engineer, and in this respect corresponded more nearly to the early engineers of England. His work as an inventor of railroad appliances, such as the eight-wheeled car, turn tables, derricks, switches, etc., was of great value. As an engineer, he, perhaps, should be classed as a mechanical rather than a civil engineer, but he was primarily an inventor and builder.

In railroad engineering, the Baltimore & Ohio Railroad held about the same position as did the Erie Canal in canal engineering. This railroad was a great enterprise and its construction extended over several years, so that it constituted a great school for railroad men. The first chief engineer of this great enterprise was Jonathan Knight, who was another example of an engineer developed from a surveyor. His father was a surveyor before him and a school teacher, and taught his son the art of surveying. Young Knight was able to secure some additional mathematical instruction in school, and at twenty-one began work as a surveyor. He secured valuable experience on canal work and when the B. & O. Railroad was organized in 1827, he was appointed to make the surveys. Knight was quite an investigator and carried on many studies on car friction, train resistance, curve resistance and the like, which he thought necessary in solving his problems. He was obliged to use much sharper curvature on this road than had ever been used before and many people doubted whether trains could be used over such a crooked road. The B. & O. construction developed railroad practice in many other ways, such as the compilation of tables of curves, earthwork quantities, etc.

Another great engineer connected with the development of the B. & O. R. R. was Benjamin H. Latrobe. He was educated for law, but entered the service of the B. & O. as engineer under Knight in 1830. Latrobe's chief work was in a design of bridge structure and in this work he developed an important type of wooden arch truss which was largely used. He had associated with him Mr. Albert Fink, a German engineer, whose type of truss is well known to all bridge engineers. Among other works with which Mr. Latrobe was connected in later years was the Havre de Grace bridge in

1863, the St. Charles bridge over the Missouri in 1865, the Hoosac Tunnel in 1866 and the Brooklyn Bridge in 1869.

This chronology brings us up to the time when school facilities became available, but before turning to the subject of school development in this country, there were two other engineers belonging to the first half of the 19th century, whose careers should be briefly mentioned. These were Col. Chas. Ellet and Jno. A. Roebling. In some respects, the careers of these men were similar. Unlike the men whose lives have already been mentioned, Ellet and Roebling secured a good engineering education. Ellet served two or three years under White and Wright on canal construction, but as soon as he could have the necessary money, went to France and studied engineering at the Ecole Polytechnique in 1830-31. Roebling was born in Prussia and was educated at the Royal Polytechnical school at Berlin, but came to this country as soon as his military service was completed. He was employed at first on canal construction, but soon became interested in the manufacture of wire rope. Both Ellet and Roebling became strong advocates of wire suspension bridges and competed for designs for the Niagara Bridge. Ellet constructed a suspension bridge at Fairmount over the Schuylkill in 1842, which was the first structure of its kind in this country. He also completed a highway suspension bridge at Niagara Falls in 1848; but the railroad bridge was built by Roebling in 1855. Roebling's last work, the great Brooklyn Bridge, made his name famous for all time.

Since the time of Roebling, Ellet, Fink and Latrobe, the ranks of the profession have included a great number of men of high standing, most of whom have had the benefit of a comparatively large amount of school training. And while there have been many examples of great success of men who have had little or no school training, the opportunities to secure such training have been many and the advantages accruing therefrom have been universally recognized.

From the sketches above given, we see that most of the early engineers of America obtained their engineering training in practice. A few had studied at West Point and a very few had secured some engineering education abroad. Many of them had, however, secured considerable schooling in mathematics and had begun their work as surveyors. School training was by no means decried, and such as could be obtained was highly prized. In respect to school training, there appears to be some difference between the early civil engineers of Great Britain and those of the United States. The former were developed generally from artisans, builders and inventors; the latter from surveyors and men who, as a rule, had considerable schooling in mathematics. Surveying in those days was a study often taught in seminaries and colleges as a part of a course in mathematics. It was a subject frequently taken up by cultured people as a matter of interest and practical utility. The four surveyor-judges already mentioned are examples

of this sort and one is also reminded of the fact that George Washington was a good surveyor. Thus from the first the work of the civil engineer in this country had been looked upon somewhat more than from the standpoint of mathematics and science than was the case in Great Britain. Perhaps it was due to this difference in the training and antecedents of the early engineers of the two countries that the attitude of the engineering profession towards college men has always been more liberal in this country than in England, for I think it may be safely stated that at no time in this country has there been any general prejudice in the civil engineering profession against school training. It was certainly not through lack of appreciation of the value of mathematics and mechanics to the civil engineer that more of the early engineers did not get a school education, but from the fact that school facilities were not generally available.

Turning now to the experience of the early engineers of this period, let us see what the schools in the United States had to offer in the way of engineering training. The first engineering school established in this country was the Military Academy at West Point, which graduated its first class in 1802. Though established for military purposes, its course of study was largely scientific and technical and many of its early graduates resigned their army commissions and entered the civil engineering profession. There was a very general demand for engineers in canal and railroad work in the period from 1820 to 1840, but in spite of this, no school was established primarily for their training until the organization of the Rensselær Polytechnic Institute about 1835. The nearest approach to technical training outside of West Point was such as was obtained by Canvass White at the Fairfield Academy, and, considering the available material at that time, it was, indeed, a very good beginning.

The Rensselær Polytechnic Institute was at first little more than a school of elementary science and in the first announcement the word engineer did not appear. But by 1835 it had developed a clear-cut course in civil engineering and the announcement of that year states as follows:

"Students of the engineer corps are instructed as follows: Eight weeks in learning the use of instruments (as compass, chain, scale, protector, level, etc.) with their applications to surveying, leveling, calculating excavations; eight weeks on mechanical powers, circles, conic sections, construction of bridges, arches, railroads, canals, running circles for railways; four weeks in calculating the quantity of water per second, supplied by streams as feeders for canals or for turning machinery; four weeks to study the effect of steam and wind as applied to machinery." This is an interesting outline and is remarkably comprehensive in topics, but from the short period of 40 weeks allowed for the instruction, the courses were evidently very short. The shortness of the course and the fact that it included elementary mathematics, physics and chemistry,

as well as the engineering subjects mentioned, shows clearly the status of engineering science at that time.

The success of the R. P. I. and the prominent positions occupied by its early graduates are well known to all familiar with the history of engineering schools. There was no question as to the value of school education at that time.

The next civil engineering school organized was founded at Union College in 1845, and, following this, the Lawrence Scientific School in 1846, and the Engineering Department of the University of Michigan in 1852, which was at once placed on an equal footing with the classical department. By this time the work of the civil engineer had come to be recognized as a distinct profession and an honorable one; and instruction to prepare young men for this profession was given a good deal of attention in the organization of several of the state institutions prior to 1860. In the establishment of the University of Wisconsin, about 1850, the intent of the Board of Regents in this direction was clearly expressed in terms showing the breadth of appreciation of educated men at that time. A chair of civil engineering was formally established, but on account of lack of funds, no one was appointed to give instruction until five or six years later.

These early schools were thus established as distinct civil engineering schools, to prepare young men for the well-recognized work of the civil engineer. They were, therefore, the result primarily of the demand for professional instruction, and were not intended to train for the manufacturing industries. Mechanical and electrical engineering had not yet been thought of. There was, however, beginning to be an insistent demand for school training in all of the various fields of the mechanic arts, and it was apparent that the civil engineering school did not fully meet this. Some attempts had been made, prior to 1860, to establish various kinds of industrial schools, the Franklin Institute, established in 1824, being one of these; but the requirements of the industries were not so clear cut as those of the profession of civil engineering and there was a great variety of opinion on the subject. No great progress was made until after the passage of the Morrill act by Congress in 1862, under which Federal Aid was given to each state by means of land grants for the establishment of schools for instructions in agriculture and in mechanic arts. This was a remarkable piece of legislation and resulted in the rapid development of schools of civil and mechanical engineering in many of the states. Among the most notable of the schools established at that time, and supported in part by the Morrill fund, were the Massachusetts Institute of Technology, Cornell University and the University of Illinois. It is interesting to note that the founders of the Massachusetts Institute proposed at first to provide industrial training in agriculture and the manufacturing industries, but when their ideas were further crystallized, the courses provided were in civil, mechanical and mining engineering, architecture and gen-

eral science. The funds received from the land grants were, in some cases, applied to existing institutions, as at the University of Wisconsin, and aided greatly in the development of the instruction already begun. In many of these early land grant schools the civil engineering course was for some time the chief or only course of study offered in engineering. Instructional material was already well organized for this work, but school instruction adapted to the mechanical industry was not so well defined.

The length of the engineering courses established in the land grant colleges and in the universities from 1850 to 1860 was generally four years. This was a big increase from the one-year course at R. P. I. in 1835. The amount of engineering instruction given depended a good deal on the money available for employing the necessary teachers. In the stronger schools the engineering instruction given as early as 1870 was not fundamentally different from that given at the preesnt time.

Compared to 1835, the increased amount of instruction was made possible by the further development of the theory of mechanics and truss analysis by such men as Rankine and Whipple, by the development of such mathematical subjects as descriptive geometry, stereometry, geodesy and practical astronomy, and by the gradual accumulation of practical information of engineering practice. The development of mechanics also carried with it more thorough instruction in mathematics and the calculus was made a part of the course. There has been comparatively little modification in these fundamental studies in the past 40 years.

In the development of the mechanical engineering course, the selection of studies has not been so simple as in the case of civil engineering. The demand for the mechanical engineer came from the manufacturing industries, from engineering shops and power plants, and the contact between school and practice was not clear. Furthermore, the value of school training was at first much less apparent than in the case of the early civil engineers and surveyors. The mechanical engineering course, following, as it did, the civil engineering course, was naturally patterned after it to a considerable extent; the same fundamental mathematics, science and mechanics were included. To these were added the study of the heat engine and other prime movers, machine construction and shop practice. The correlation between the industries themselves and the school and student of mechanical engineering was not a simple problem. It was entirely different from the problem connected with civil engineering instruction, but by persistent and farsighted work on the part of the early educators, the value of college instruction in mechanical engineering came to be appreciated and opportunities were opened to the graduating students. These early leaders in mechanical engineering instruction distinctly aimed at *professional* instruction and their work went far toward establishing the profession of mechanical engineering on a basis similar to that of the older profession of civil engineering. A very im-

portant influence on the character of mechanical engineering instruction was the U. S. Naval Academy, established about 1850, and from which several of the early teachers of mechanical engineering were drawn.

When the electrical engineering course was established in the early '80's, it followed as a matter of course that the special instruction should include, primarily, advanced physics and applied electricity, the only difference of opinion being as to the degree of differentiation from the mechanical course. And in more recent years we have the chemical engineering course constructed with the same skeleton of mathematics, mechanics and science, but with both chemistry and mechanical engineering included in the technical instruction.

The development of the various engineering sciences has been brought about largely by co-operation between the practicing engineer on one hand and the investigator and teacher on the other. In many cases it has been the engineer, who, recognizing the need of more accurate information along his particular line, has carried out some valuable series of experiments. The great work of James B. Francis is an example of this kind. More frequently, however, it has been the teacher and investigator who has discovered the laws and underlying principles and has placed the subject on a rational and teachable basis. The engineering profession is full of men who are thoroughly scientific in their methods and who have just as keen a preception of the scientific value of their studies and experiments as the man in the laboratory; and they are apt to have a better appreciation of its practical value. On the other hand, there are many teachers and experimenters in college laboratories who are thoroughly practical in their methods and their interpretation of the results of their studies. Frequently, however, they have not the practical experience sufficient to make their work of maximum value without the co-operation of the practicing engineer. That such co-operation is frequent and cordial is indicated by the vast amount of work now being done by the various committees of our national societies. On most of these committees there will be found working together both the engineer and the teacher and investigator and their viewpoints are so similar that it is difficult to identify, by listening to a discussion, which of the members are practicing engineers and which are primarily investigators. The spirit of co-operation in this direction is all that could be wished.

The result of all the study and research of the past 30 years has been to furnish a mass of scientific information of use to the engineer which is far greater than can possibly be taught in a four-year course, even if organized in the best possible way. And a large part of this information is more scientific and fundamental in character than most of the technical material given in the four-year course of 40 or 50 years ago.

In selecting his material, the teacher must in general adhere

to the more fundamental subjects and to those practical subjects that have been placed on the most rational basis. In these days of books and periodicals, school instruction, consisting primarily of descriptions of engineering practice, cannot profitably be carried very far. The selection of material at the present time is, however, not so much a choice between scientific, as distinguished from purely practical and descriptive material, as it is a question of the best subjects to teach a young man for such a period of time as it will be profitable for him to spend in a school.

And this brings us to the problem of the engineering school of the present day. What subjects should be taught, how should they be taught, and what should be the length of course so that the best results will be secured in the various lines of work in which engineering training is desirable? The curricula of the later engineering courses have, in general, followed the lead of the civil engineering course; they have been planned primarily to give a professional education, but is it certain that they are the best adapted to promote success of the graduates in the industries, as superintendents, managers and technical business men? Perhaps they are, but I think that educators do not feel quite sure about it. In this direction, the value of a college education has often been questioned, and it is along these lines that men like Crane and Taylor have urged their criticisms.

The modern demand upon the engineer is greater than formerly; more and different things are expected of him. Modern life is becoming so complex that we are confronted on every hand with activities requiring for their efficient administration not only managing and executive ability, but technical knowledge as well, and the engineer seems to be the man best fitted for the task. Broadly speaking, the work of the modern engineer is coming to be more and more the work of management, not only of the materials and forces of nature as defined by Tredgold, but management of men, management of industries, management of cities. To provide the best possible education for such duties is the special problem of the engineering educator today.

These are some of the questions which are now being asked:

Should foreign language be required of all engineering students?

Should the same old backbone of mathematics and mechanics be taught to all alike?

To what extent can and should management be taught in school, not simply scientific management, but rather the science of management?

To what extent should actual contact with the industry be required during the school course?

How can broad and sympathetic understanding of others' points of view be cultivated in school?

How can the various traits of character be best developed that are essential to success in business relations and that will promote the best citizenship.

In the solution of this educational problem, the engineering educator needs the aid of practical men, and especially of those in touch with the industries. He welcomes their criticisms and suggestions, and it is only by the same co-operative effort that prevails along investigative lines that the best solution will be reached.

ADDITION TO THE UNION LEAGUE CLUB

By Frank E. Brown, Assoc. W. S. E.

Presented December 11, 1916.

The property owned and occupied by the Union League Club of Chicago is located on the southwest corner of Jackson Boulevard and Federal street. The lot has a frontage of approximately 100 ft. on Jackson boulevard and a depth of 149 ft. along Federal street. On the north 100 ft. of the lot is the original club building facing on Jackson boulevard. This is an eight-story building of ordinary construction supported on interior columns and bearing walls. The building on the south or rear 49 ft. is skeleton construction with steel beams and girders and cast iron columns, and, until the late addition, was eight stories in height. In this rear building are located the boiler room, a billiard room, a laundry, a kitchen, a bakery and the servant quarters, whereas, in the front building there are lounging, smoking and dining rooms, a library and sleeping quarters. These facilities, although quite extensive, did not provide accommodations for the club members who were athletically inclined. The new addition then was made for the purpose of providing a swimming pool and gymnasium and the usual accessories.

The club intends at some future date to tear down the present front building and put up a more modern structure. An existing plan of the complete future building contemplates making the present rear fireproof section a part of the final structure. With this in view, no extensive alterations to the present front building could be considered at this time and the location of the swimming pool and gymnasium were, therefore, restricted to the rear building.

One would naturally expect that a swimming tank would be located in the basement. In this case, however, it was put on top of the old rear building. A considerable space unobstructed by columns was required, which was impracticable to obtain in the basement on account of the interference with the old foundations and power plant and the necessary shoring and supporting of the old columns. Three stories were added to the old building to provide the necessary space for the swimming pool and gymnasium.

Figures I and II show the architectural layouts of the new addition.

On the eleventh floor, shown on Fig. I, is the swimming pool, which is 30 ft. wide and the regulation length of 60 ft., and has a water depth of 8 feet and 6 in. at the plunge and 4 ft. at the shallow end. On the same floor are located a lounging room, a toilet, shower baths and a turkish bath, including steam, electric bath and massage room. In the penthouse over the turkish bath, is a large restroom provided with cots. Directly over and covering the entire area of the swimming pool, is a skylight. This skylight is a double one,—the top lights being built with a straight pitch to

each side from the center of the pool, while the inner lights of amber glass are in the form of an arch. The abundance of light provided by this skylight makes the pool especially attractive.

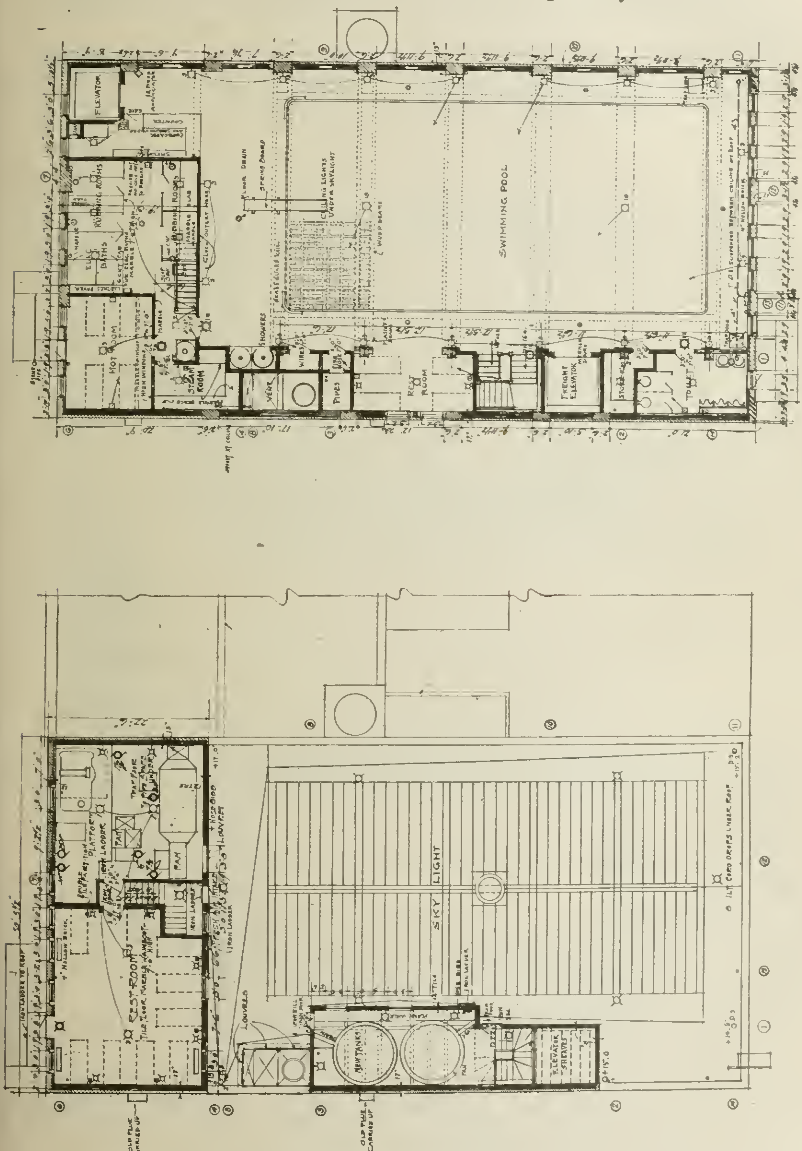


Fig. I

On the 9th floor, shown on Fig. II, is the gymnasium, which is 33 ft. and 6 in. wide by 97 ft. long, and has a clear ceiling height of 15 ft. The gymnasium is provided with the necessary apparatus

for the various forms of exercise, including indoor ball and basket ball.

A large part of the 10th floor is taken by the lower part of the swimming tank. The remaining space is given over to locker and dressing rooms.

The framework required to support this addition involved some features not ordinarily encountered in building construction. The

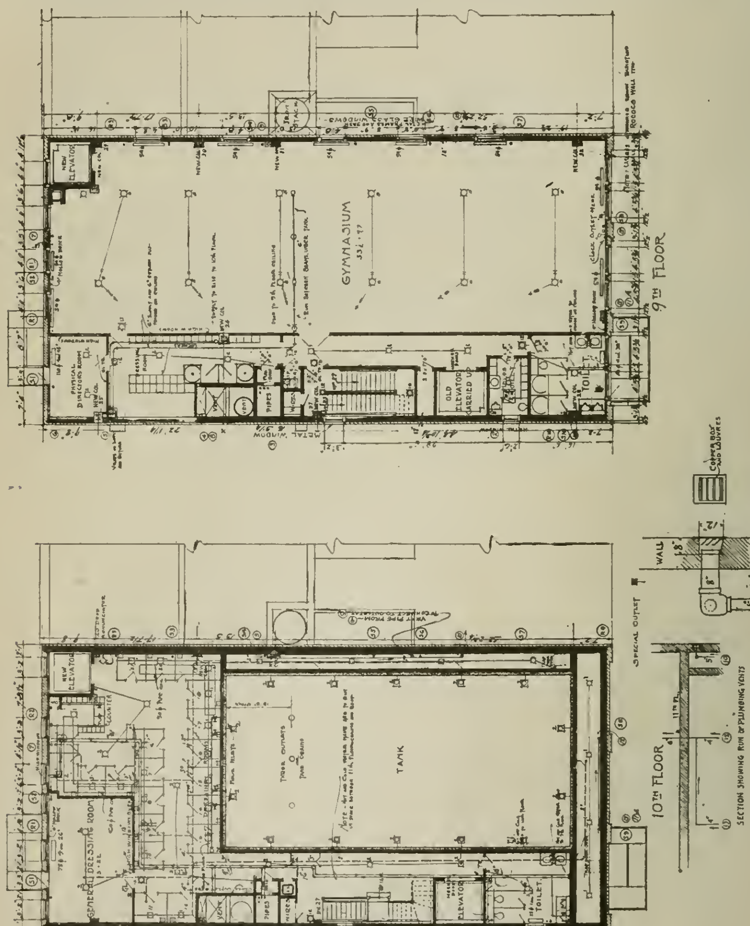


Fig. II

old columns were good for very little additional load, and being cast iron, could not be reinforced to any great extent. Removing the old columns and replacing them with new steel columns was out of the question, as besides the expensive shoring necessary, the old foundations were inadequate and of such character that they could not be easily reinforced.

The old foundations and the old cast iron columns below the seventh floor, however, were sufficient to support the new ninth floor. In the original design provision had been made for nine stories, six of which had been built as permanent and a seventh put on as a temporary story. Later the 7th story roof was strengthened and made the 8th floor, but the 7th story columns were left as originally constructed. This left them weak for the new 9th floor, and they were strengthened by filling and enclosing them with concrete, reinforced with hoops and vertical rods. The old 8th story columns and roof were removed and the new 9th floor built at the new level. This was supported with the exception of the east and west walls and adjacent floor areas on new 8th story columns resting on the old 7th story columns reinforced as stated above. The 9th floor was built of straight beam and girder framing with flat tile arch floor construction.

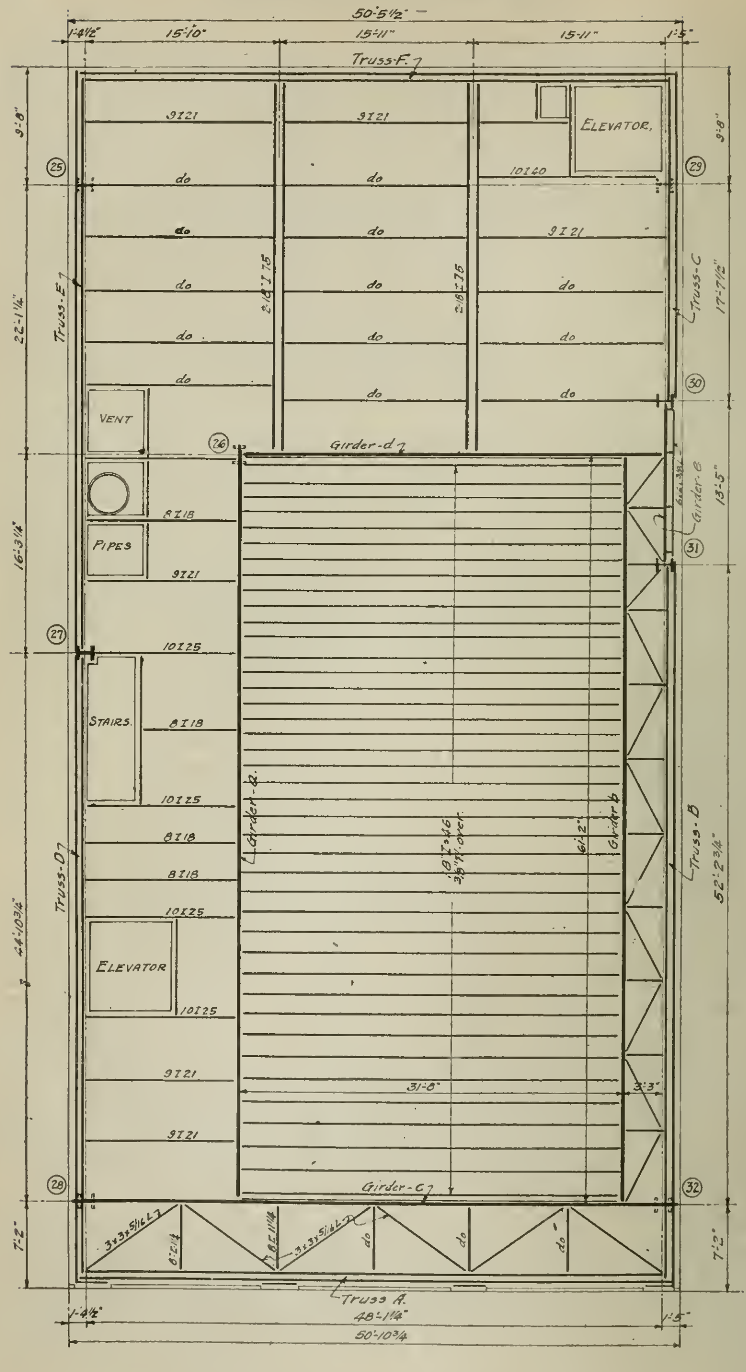
The 10th and 11th stories were supported entirely independent of the old columns. Eight new columns were used. These had to be located so they would clear the old foundations and not obstruct important rooms in the old building. In only one case could a column be located at a corner of the tank or in the interior part of the building and none could be placed in either the east or west walls. Considerable cutting and reframing in the old building was necessary in order to install the new columns. The old concrete floor slabs had to be cut, the old walls chased and the old spandrel and floor beams cut off, spliced and reframed to the new columns. Since seven of the new columns were located in the walls, some especially difficult cutting and reframing of old spandrels was required. In the east and west directions the old spandrel and wall beams served as braces for the new columns, but in the north and south directions new beams were added at all floors to tie into the old floor framing. In general, these braces were 12 in. channels laid flat and bolted to the top flanges of the old floor beams.

In Figs. III and IIIa the framing plans for the 10th and 11th floors are shown. These show the location of the new columns,—three in the south wall, four in the north wall and one at the southwest corner of the swimming tank. This arrangement of columns, of course, necessitated special framework.

The sides of the swimming tank were formed by plate girders, approximately 11 ft. deep. These support parts of the 10th and 11th floors and roof, as well as the 800,000 lbs. of water in the tank.

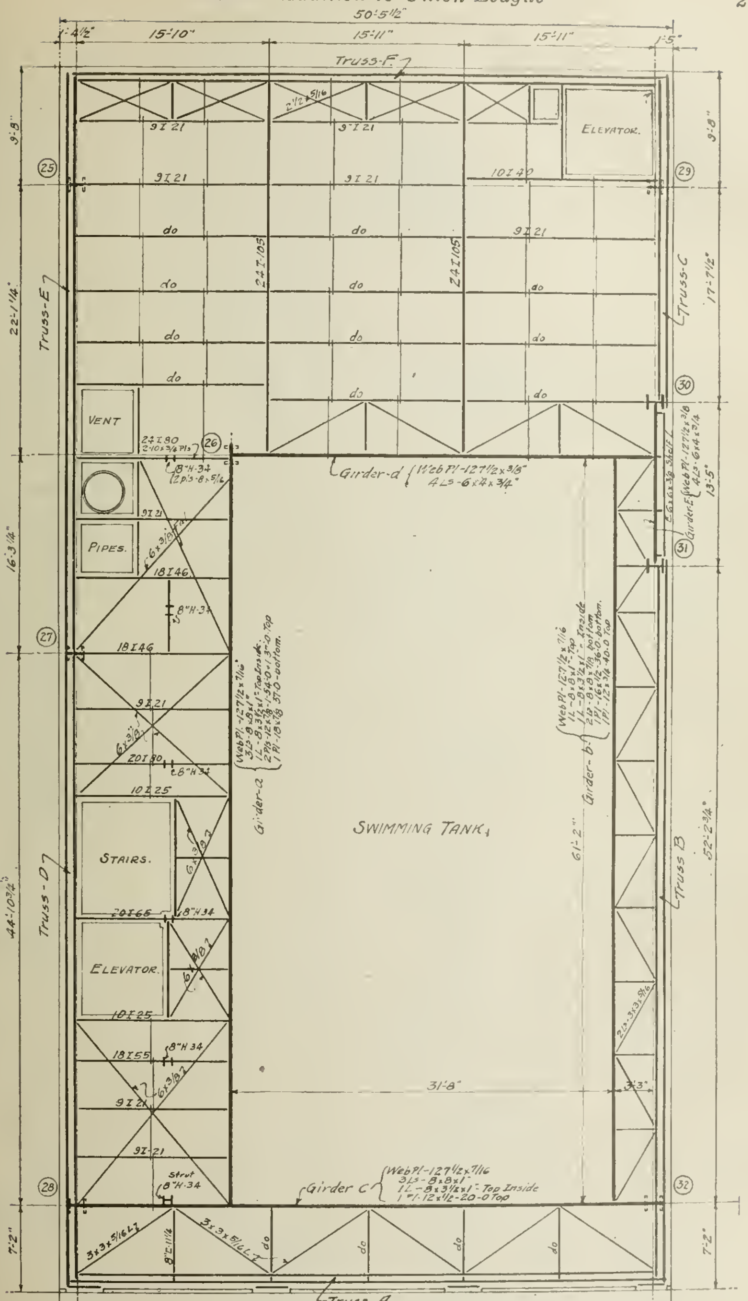
The bottom of the tank was formed by 18 in. I beams spaced 13 in. to 24 in. centers with 3/8 in. plate over the entire area, riveted to the top flanges of the I beams and to continuous angles on the sides of the girders.

A system of trusses in the 10th story around the four sides of the building was used to support the walls and floors above and the east and west walls of the 9th story and the adjacent 9th floor areas. The trusses in the east and west walls were framed to trusses in the side walls which cantilevered over the new columns located



10TH FLOOR FRAMING PLAN

Fig. III



11TH FLOOR FRAMING PLAN.

Fig. IIIa

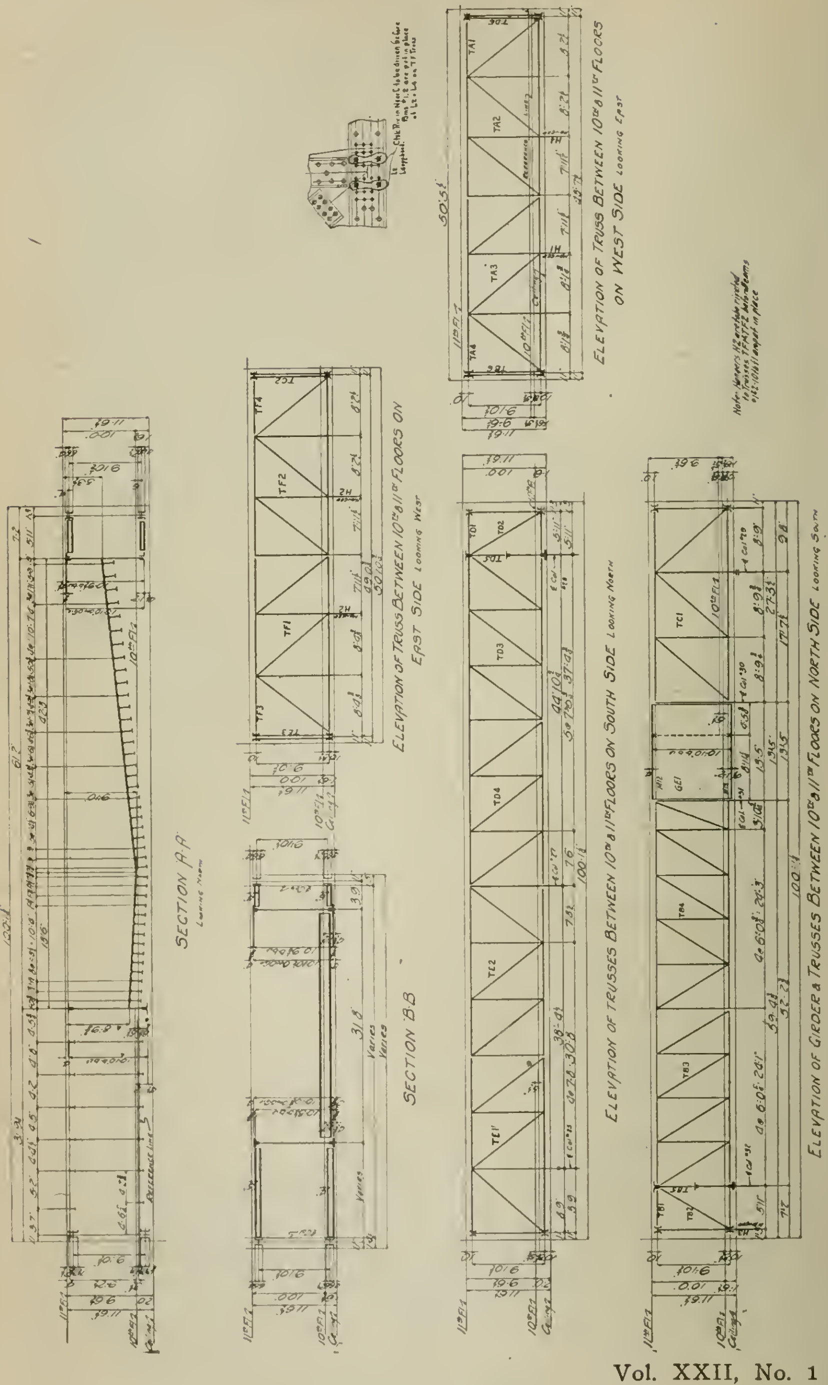

SECTION A-A
SECTION B-B
ELEVATION OF TRUSS BETWEEN 10TH & 11TH FLOORS ON EAST SIDE
ELEVATION OF TRUSS BETWEEN 10TH & 11TH FLOORS ON WEST SIDE
ELEVATION OF TRUSSES BETWEEN 10TH & 11TH FLOORS ON SOUTH SIDE
ELEVATION OF GIRDER & TRUSSES BETWEEN 10TH & 11TH FLOORS ON NORTH SIDE

Fig. IV

seven and ten feet in from the building lines. Line diagrams of these trusses are shown on Fig. V. For truss "C," where the balancing arm was short, the cantilever load produced an uplift on column No. 30. The downward load on this column from the tank girder was much greater than the uplift, but advantage was taken of the reduction in designing the column. The trusses were built of double channel section placed 7 in. back to back and laced. An investigation of the secondary stresses showed combined primary and secondary stresses in several members of truss "C," which were higher than was considered safe. The sections of these members were increased by adding side plates.

The trusses were set 6 in. eccentric with the columns. This could not be avoided as to have put the trusses on the center line of column and used brackets for supporting the walls, would have taken valuable space in the 10th story and interfered with the elevator clearances. The new columns could not be moved further out because on the south it was necessary to clear off the lot line and on the north it was undesirable to cut entirely through the old bearing wall below. The eccentric effect was eliminated on columns No. 28 and No. 32 by connecting the trusses to the tank girder and resting the girder on top of the columns. On columns No. 25, 27, 29 and 31, the eccentric effect, reduced to equivalent direct load, was eighty to one hundred per cent of the direct load. On column No. 30 the eccentric load was an uplift.

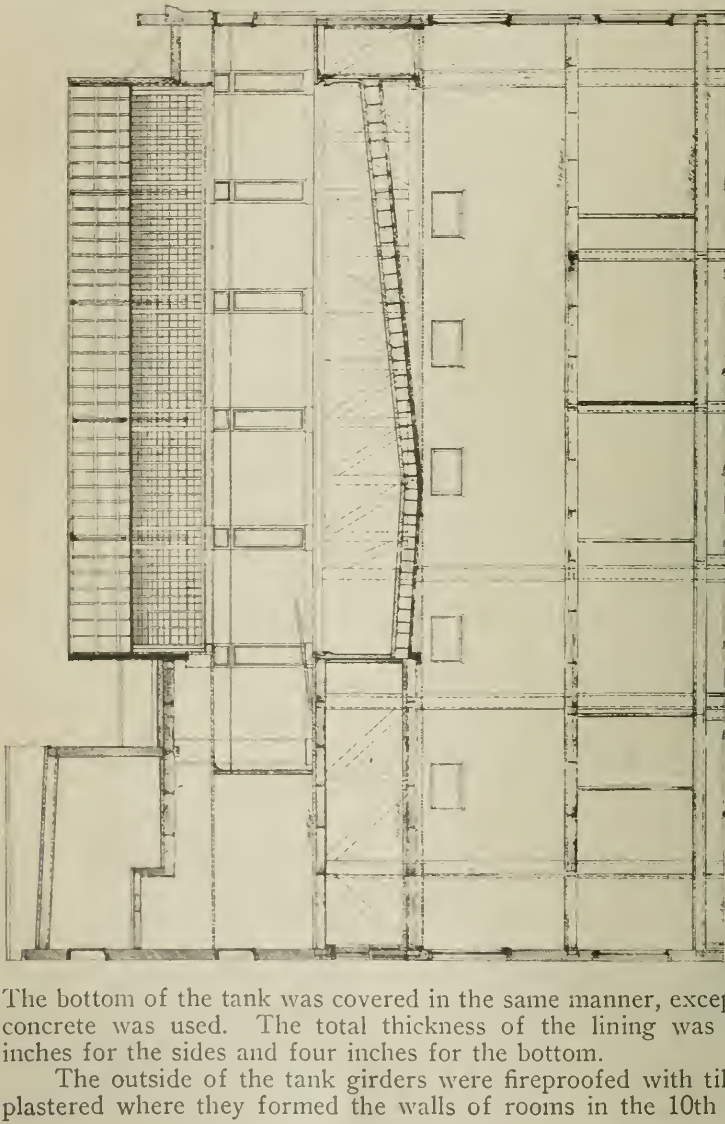
Lateral bracing was put in at the 10th and 11th floors between the wall trusses and the tank girders. The lateral pressure of the water in the tank was considered in determining the amount of bracing required for the top flanges of the girders.

The penthouse and roof framing was supported on struts to the 11th floor and on the exterior walls. This framing was somewhat involved on account of the many different levels of floor and roof. The skylight was framed by light steel trusses and purlins. The upper skylight units were supported directly on the purlins while the lower or arched skylight was hung from the purlins and the bottom chord of the trusses.

The walls of the 10th and 11th stories were built with 4 in. brick facing backed by Dennison tile. Every fifth course of brick was a header course. The tile was used in order to lighten the loads carried by the trusses. In the 11th story, solid brick piers were used at points where the heavier roof and penthouse loads were supported.

The lining for the tank was a subject of much discussion. The original specifications called for a watertight steel tank lined with membrane waterproofing, concrete and tile. It was intended to make the steel tank watertight by caulking and welding. This the general contractor was reluctant to do, so a lead lining was substituted. The rivet heads on the inside of the girders were flattened to ½ in. and 1½ in. of cement was put on with a cement gun. Next to this sheet lead, weighing four pounds per square foot or about

one-sixteenth inch thick, was placed. The sheet lead was fastened by tacking at the joints to wood strips which were set in the cement. The joints were then soldered to make them watertight. Membrane waterproofing was placed next to the lead, then four inches of cement was put on with the cement gun. The lining was then faced with ceramic tile one-quarter inch thick, set in cement mortar.

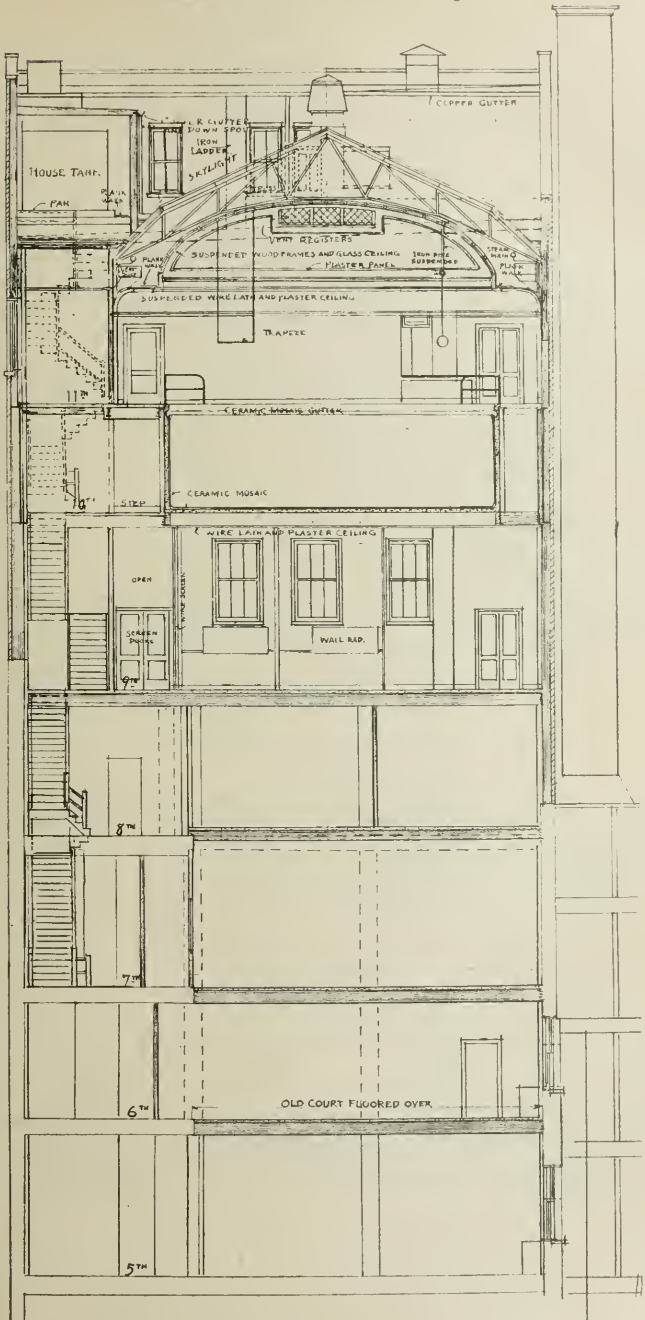


LONGITUDINAL SECTION A-A.

Fig. V

The bottom of the tank was covered in the same manner, except less concrete was used. The total thickness of the lining was seven inches for the sides and four inches for the bottom.

The outside of the tank girders were fireproofed with tile and plastered where they formed the walls of rooms in the 10th story



SECTION LOOKING WEST

January, 1917 Fig. VI

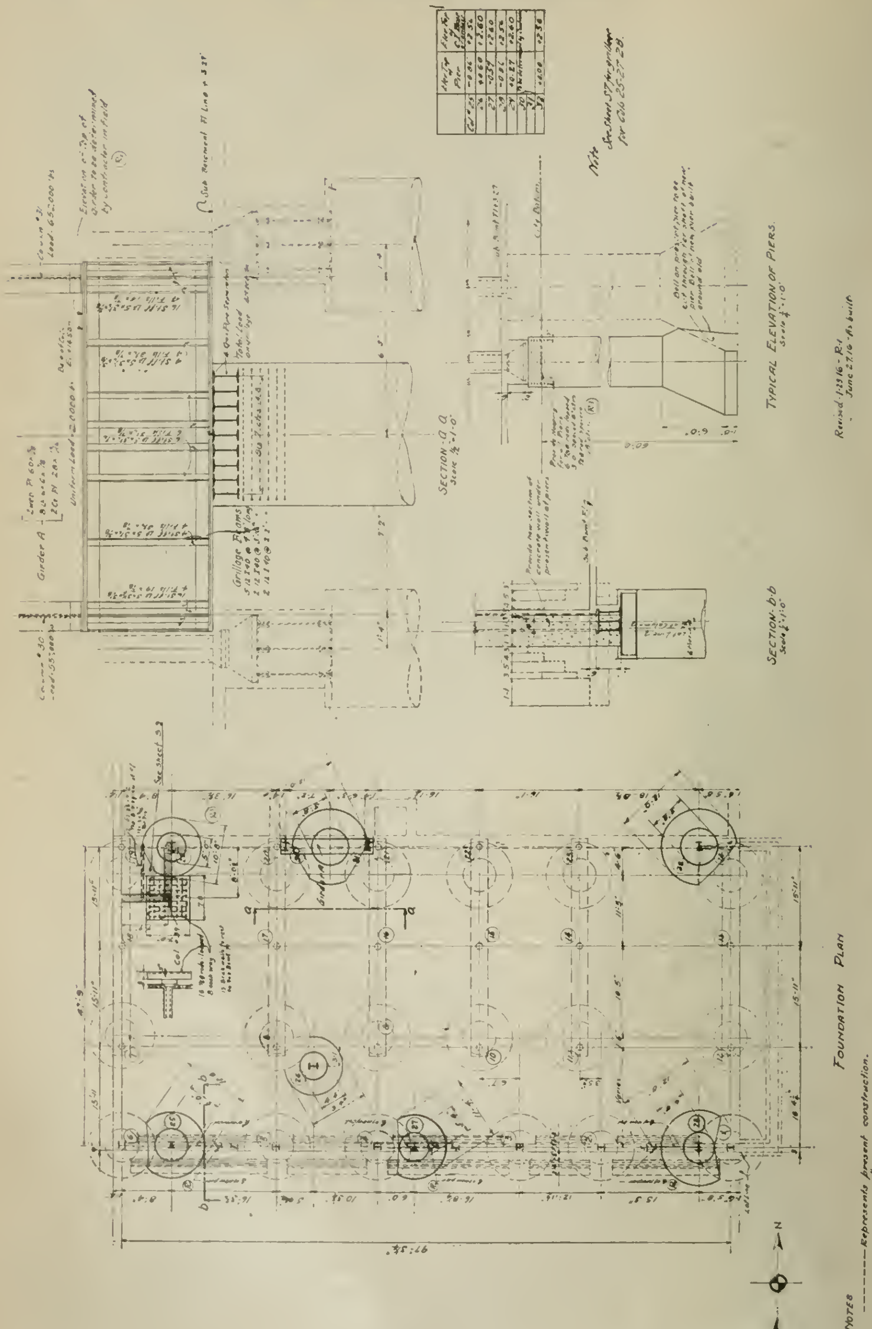

FOUNDATION PLAN
TYPICAL ELEVATION OF PIERS
SECTION a-a
SECTION b-b
Grillage Beams
Girder A
NOTES
Represents present construction.

Fig. VII

The lower flanges of the beams which formed the bottom of the tank were covered with tile fireproofing. The 10th and 11th floors, outside the tank, were flat tile arches with concrete fill. The 10th floor was cement finish and the 11th floor was ceramic tile.

Since the underside of the tank and 10th floor were at several different levels and a flat ceiling was especially desirable for the gymnasium, a suspended ceiling was used covering the entire 9th story area.

The water purification system used for the tank was arranged so that the water would be continually in motion. Three four-inch outlets placed in the bottom of the tank connect to a six-inch main. This main leads down to a direct acting duplex steam pump in the basement. The water is then pumped to a filtering apparatus. Here a small per cent of alum is added which coagulates the fine suspended matter. After passing through a quartz filter, the water goes through a heater. From the heater it is forced up to the 11th floor and after passing through a violet ray machine is returned to the tank. The violet ray machine is located on the floor at the east end of the tank. It is constructed so that the water passes in thin filaments over mercury vapor lights which produce the ultra violet rays and kill the bacteria. By this method of continuous flow, the water is kept purified and at a constant temperature. A complete circuit is made in twenty-four hours. It is also intended that the tank be emptied once in two months and the bottom and sides thoroughly cleaned. About two hours are required to empty the tank and about twelve hours to fill it.

The foundation plan shown on Fig. VII shows both the old and new work.

The south wall is a party wall between the Union League Club and the Engineers' Club Buildings. The original wall, four stories in height, supporting the floors of the Engineers' Club Building, is on a spread foundation. Above the 4th story the wall is supported on columns. Old columns 1 to 6 inclusive are supported on concrete piers which are five feet four inches in diameter at the top and extend to hard pan sixty feet below datum, where they are belled out to ten feet six inches in diameter.

The north wall, eight stories in height, supporting the floors of the front building is on a spread foundation. The old interior columns and the old wall columns are carried on steel girders running in the north and south direction under the boiler room floor. Each girder supports three columns and rests on two concrete piers. These are five feet four inches in diameter at the top and extend to hard pan, where they are belled out to ten feet six inches in diameter. The piers are back four feet six inches from the center line of the north wall columns and clear the spread foundation of the north wall.

Seven new concrete piers were constructed to carry the eight new columns. These varied in diameter at the top from four feet four inches to six feet, and extended to hard pan at the same eleva-

tion as the old piers where they were belled out to a diameter equal to two and one-eighth times the diameter of the shaft. The bells of the old piers were cut through where they interfered with the shaft of the new piers, but the new bells were built over and around the old.

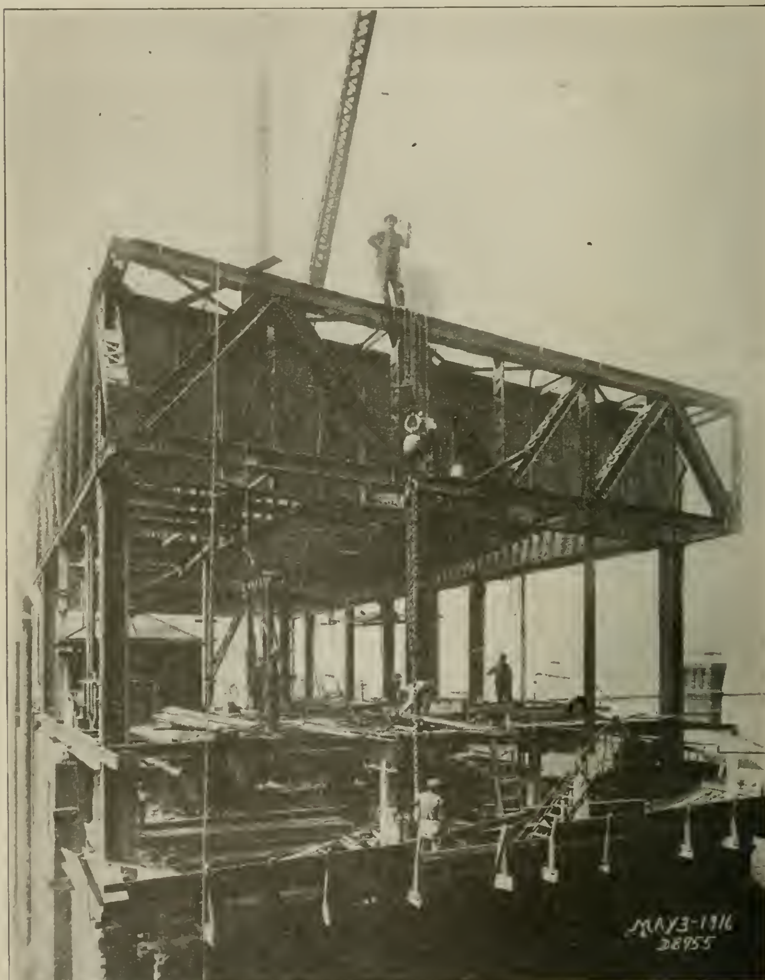


Fig. VIII

Columns No. 30 and 31, which could not be placed on separate piers on account of interference with the old piers were supported by balancing them over one pier. A steel box girder, five feet deep, resting on I beam grillage set on top of the pier was used. This is shown in Section "A-A" on Fig. VII.

In sinking the caissons, precautions were taken to prevent settlement of the old spread foundations. It is generally known that in sinking caissons there is almost always some settlement of the adjacent soil toward the lagging. Evidence of this is given by the

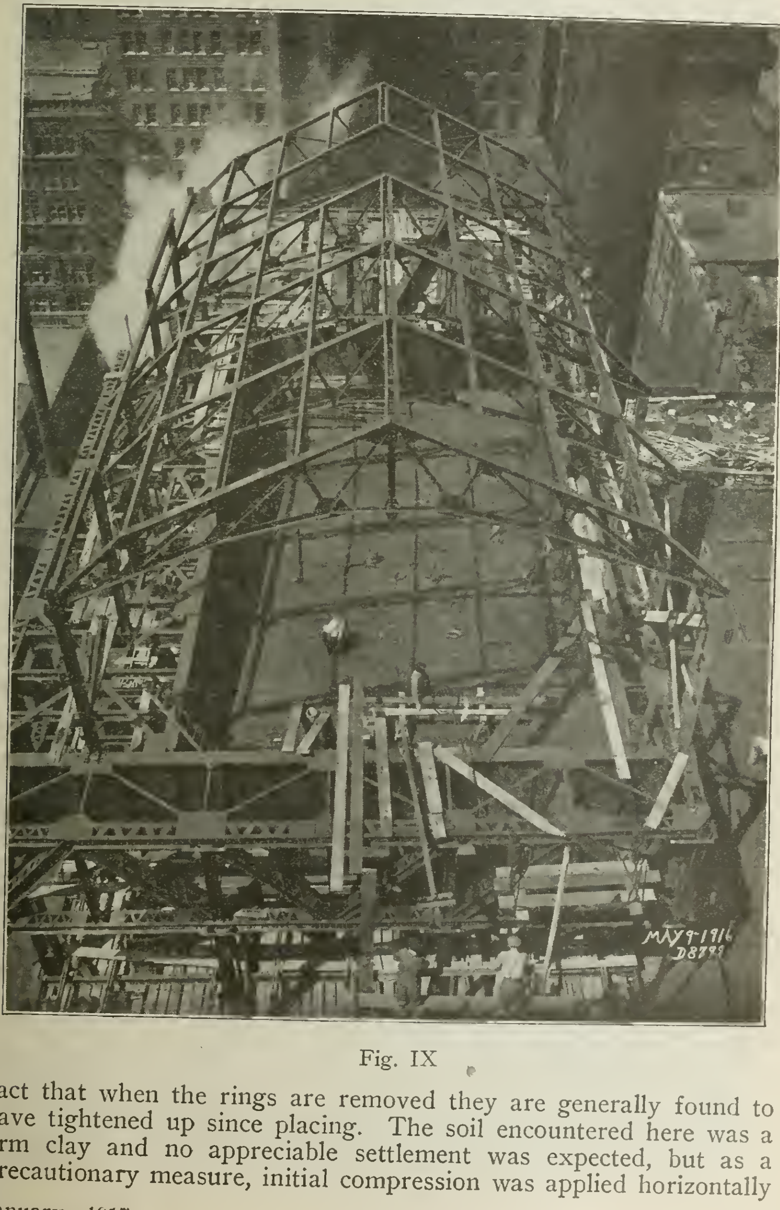


Fig. IX

fact that when the rings are removed they are generally found to have tightened up since placing. The soil encountered here was a firm clay and no appreciable settlement was expected, but as a precautionary measure, initial compression was applied horizontally

Fig. X

to the soil as the caissons were sunk. This was done by using two sets of diaphragms and four jacks to each set of lagging.

In building this addition, the effort was made to interrupt as little as possible the club's use of the old building. The power plant, billiard room, kitchen, bakery and serving quarters were continued in use throughout the period of construction.

The following procedure was adopted:

The new foundations were first installed, dust-proof enclosures four feet square were then built on each of the old floors around the places where the new columns were to be put through. These were built of 2 in. by 4 in. studs with paper board inside and out.

Fig. XI

The floors were next cut through and the walls were chased the full height. The old spandrel beams were then shored and cut with an oxyctylene flame. The old 8th story roof was removed and a derrick was set up on the old 8th floor. The new columns in one and two story lengths were raised from the street to the 8th floor and lowered through the openings and set in place. The old spandrel girders were then spliced and connected to the new columns and the braces to the old floor beams were installed. The splices in the columns and spandrel girders and all connections to the old steel work were made with turned bolts. As soon as all connections were made in the old part of the building, the columns were boxed in and fireproofed with 3 inches of stone concrete. The old cast iron 7th story columns were reinforced, then the erection of the new framing above continued. All of the steel work was erected by the one derrick without changing its position. The heavy trusses and

Fig. XII

girders were erected in twenty-foot lengths and required special shoring and bracing to hold them in place until the splices were made. When the steel was all in place, the construction went forward to completion in the usual manner.

DISCUSSION.

H. J. Burt, M. W. S. E.: It certainly was a complicated piece of work, not only for the designer but for the builder. And it was carried through very successfully and satisfactorily. I am sure that all of us who had anything to do with it were mighty glad when it was finished.

With reference to the tank, there was a good deal of discussion as to the proper method of making it watertight. I favored very strongly making the steel tank itself watertight, but it involved a

good many difficulties on account of the many bad corners that would have to be fitted. The tank material itself was very heavy, and our idea was that it would probably be easier to solder the joints with the torch rather than to caulk it. The contractor was so very insistent on changing the method of making it watertight, that he was allowed to do so, and substituted the lead lining instead of making the steel tank watertight.

After the tank had been assembled, a heavy rain occurred and even without any caulking the tank held all the water that fell into it and had to be bailed out.

However, after it was completed, with all the precautions that have been described, it leaked. The leak was not a very serious one in quantity of water, perhaps a couple of bucketsful a day came from it. Two or three weeks were spent in trying to locate the cause of the trouble. They did not locate it, and the leak stopped after a time, either by the sediment from the water, or by rusting. The supposition is that it leaked at one of the connections to the tank.

It is interesting to note the method used in trying to locate the leak. A piece of canvas was put over various portions of the bottom of the tank, and the edges of it weighted down, the idea being that it would form a sufficiently close contact with the bottom so that the water would not run in under the edge. Although this method did not locate the leak, it did prove to be a watertight dam. It was placed over one of the outlets of the tank, then that outlet was opened and no water came through. Now the tank appears to be absolutely tight and in a very satisfactory condition.

Mr. Brown, I think, did not state specifically in reference to precautions against settlement, that no settlement of consequence occurred in surrounding property. On the party wall between the Union League Club and the Engineers' Club, there was a measurable settlement of a very small fraction of an inch. None of the walls of either the Union League Club Building or of the adjacent buildings were shored on account of the work.

Walter S. Lacher, ASSO. W. S. E.: It would be interesting to know how successful the builder was in avoiding any discomfort or inconvenience to the occupants of the building. I suppose the only thing that they could not avoid was the noise of the riveters.

Mr. Burt: No department of the club except the laundry was put out of business. Of course, they were disturbed to some extent. The laundry was in the story which was rebuilt, and of course had to be removed.

W. W. DeBerard, M. W. S. E.: Were the sides of this tank used as girders? Did that have anything to do with the contractor's wanting to change over to the other method of waterproofing? If the sides of the tank were used as girders, there would be a measureable deflection no doubt when filled with water. When the water is let out, that load would be lifted, and the girder would go up again. Possibly there might be enough motion to make the tank leak.

Mr. Brown: The girders which form the sides of the tank were, of course, used to support the weight of the water and floor. It is my opinion that the deflection of eleven feet deep girders on sixty feet spans would be too little to effect the caulking of the joints and cause leakage. A good many cases can be found where riveted and caulked steel work has proven entirely satisfactory in holding water.

I believe I did not mention in my paper that this tank, besides being used as a swimming tank, is equipped to be used as a sprinkler tank as well.

W. W. DeBerard: That is, for the fire system?

Mr. Brown: Yes, for the fire system. The building is equipped with a partial sprinkler system. There are sprinkler heads in the halls, corridors, stairways and elevators, but none in the bed rooms. For such a system for a building of this size a 20,000 or 25,000 gallon tank would be usual, but in this case we have a tank of over 100,000 gallons.

J. W. Lowell, ASSOC. W. S. E.: I would like to ask Mr. Brown if asphalt or tar was used in the membrane waterproofing and what were the reasons for their choice.

With reference to the swimming tank as a fire protection, it seems to me that if the tank is emptied every two months and it takes twelve hours to replace the water again, the tank during that period is of no use for fire protection. I wonder if this affects the fire insurance rating of the building and its contents.

Mr. Brown: The reason for the choice of the particular make of membrane waterproofing used was probably a commercial one. I think it was asphalt and the fabric used was a cotton fabric. It was the "Minwax" waterproofing. The swimming tank is the secondary source of supply and the emptying of it does not affect the insurance rate. The primary source of supply is a 1,000 gallon fire pump, which is kept in continuous operation. The swimming tank does not cut in until the number of sprinkler heads open exceeds the capacity of the pump or in case the fire pump is shut down for any reason.

Chairman Lacher: I would like to ask whether the space between the girders and the trusses on the east and north sides of the building on the 10th floor is used for any purpose?

Mr. Brown: It is not used for any purpose.

Chairman Lacher: That is waste space?

Mr. Brown: Yes, it is sealed, except for a trap door through the ceiling to give access for inspecting the sides of the tank and the pipes and connections.

J. W. Pearl, M. W. S. E.: I failed to understand whether the contractor, in abandoning the method of construction which involved caulking the joints in the steel tank, substituted the watertight lining and waterproofing method described at the same price as the original construction, or whether the change afforded an opening for a bill of extras.

I have found it quite difficult to produce permanently water-tight joints in tanks built of hard steel plates and angles, but no trouble when the material used was soft steel.

The details of construction of the Union League swimming pool would convey to the layman, or unsophisticated, the impression that steel tanks with riveted and caulked joints cannot be relied upon to hold water. The inquisitive minded might then inquire which of the sheet lead soldered at the joints, Minwax waterproofing, or the tile protection is the most dependable element.

It appears to be a case in which, if the tank had proved to be watertight, each element could claim the honor of success, and when it failed, all would be ready to not mention it.

The millions of steel boilers, boats, tanks and other constructions, in almost every conceivable shape, for various services and all practical pressures, that are in daily use almost everywhere with riveted and caulked joints, makes it difficult to imagine a more reliable detail where perfect welding is not practicable.

If the effect of variation in deflection when filled and empty was feared, consider the common steel ore carriers on the lakes that deflect over two feet between the lines when empty and loaded, when receiving and when discharging cargo in quiet water, and a greater unknown amount when out in a rough sea. Consider also the body of a modern locomotive and the hull of a submarine, and the service the riveted steel joints in these constructions must deliver and remain tight.

Another point. It has been frequently urged that it is impossible to put these wells or caissons down for foundations without producing serious settlement in adjacent material at a higher level. The successful construction of caissons for this work, without material settlement of the ordinary foundations under this and adjacent buildings, seems to prove that caisson foundations can be put in without letting adjacent buildings down. Is that true?

Mr. Brown: Yes, these caissons were successfully constructed with little or no shoring of adjacent walls and columns on spread foundation, with no appreciable settlements. One thing that can be said about the construction of the caissons is that in this case we had a good hard clay soil to deal with, where in more troublesome cases you have either soft clay or quicksand.

Chairman Lacher: Isn't it a fact that caissons have been repeatedly placed under buildings that were standing, and simply a question as to the settlement of the adjacent building, where the building might be liable to damage, rather than the case where the building eventually comes down and the building is simply allowed to stand long enough, or to obtain some use of it until it is absolutely necessary to tear it down? And Mr. Pearl raised the question of the construction of the caissons under the adjacent buildings. My understanding is that those caissons have been repeatedly carried down underneath a standing building. I didn't know there was any question about that at all.

Mr. Brown: I think Mr. Pearl's point probably was the fact that there was not any great amount of shoring done, practically none in connection with this work, although it was immediately adjacent to bearing walls and columns on spread footings. This entire north building, the original club building, rests on spread footings, and I believe the soil pressure is probably *considerable higher* than we use now. I think a case like this where the only soil that was removed was that within the caisson and the soil encountered was all firm, is quite different from those in which considerable settlement occurs. In cases where settlement occurs the soil encountered is either soft clay or quicksand or there is a large flow of water. Also there is the general excavation for basement which we did not have here. The method used here of applying horizontal pressure prevented any settlement of the firm soil around, but of course would not have prevented a flow in at the bottom in case a soft or running material had been encountered.

Mr. Burt: On this question of settlement, I am of the opinion that most of the cases of bad settlement that we see around town are due rather to basement and sub-basement excavation than to the digging of the wells for the piers. That is the conclusion that we have reached after giving a good deal of attention to it.

We had a building on South Michigan Avenue five years ago, where the material all the way to rock was soft. It was a soft clay for the upper forty or fifty feet, and the balance of it was a running material. In one of the wells I had some rough observations made, and found that we were taking out three or four times as much water as we were of solid material. Yet the settlement that resulted from that operation did not extend more than about forty feet away from the building site. The building adjacent to it had to be shored up, but that was anticipated. There was no deep excavation other than the wells themselves. There was only one basement under the building, and that was not of an unusual depth. So that it appears that the settlement that may be expected from the wells is not very great, even under such adverse circumstances.

G. C. D. Lenth, W. M. S. E.: I understood the speaker to say that the caissons were carried down to hard pan, about —62. How far is rock below that?

Mr. Brown: That I do not know.

Mr. Lenth: You did not make any borings?

Mr. Brown: The foundations for the old part of the building were on this hard pan, about —60 or —62, and the new piers were carried down to the same elevation.

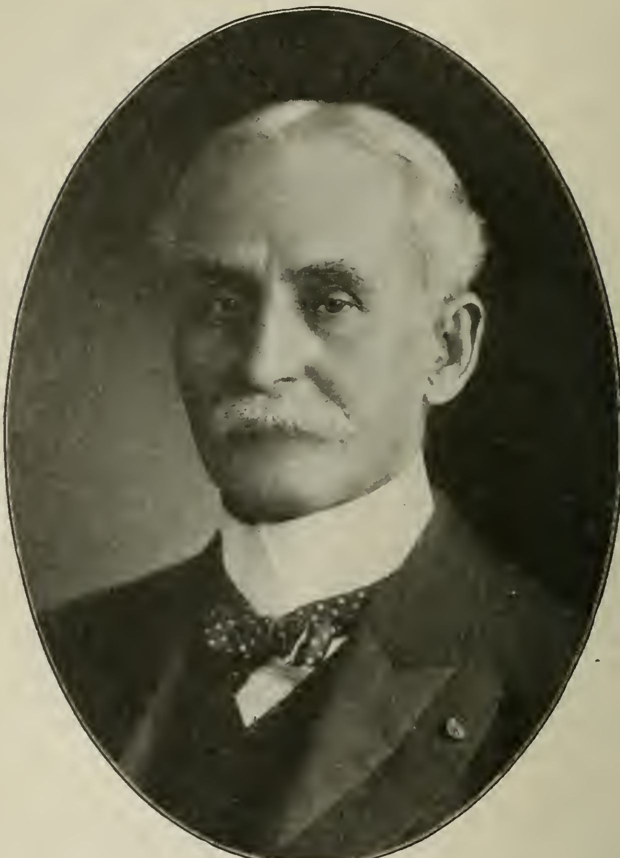
Mr. Lenth: You do not know whether that layer of soft clay, which is usually above the rock, was about 10 below there or not?

Mr. Brown: I believe the layer of hard pan is about 15 feet thick.

IN MEMORIAM

GENERAL WILLIAM SOOY SMITH

Died March 4, 1916.



When taps sound for the light of life to be put out the General obeys as submissively as does the humblest private who was ever obedient to his command. For Brigadier-General William Sooy Smith taps sounded March 4th, 1916, and the light of his life went out in his home in Medford, Oregon.

General Smith was born July 22nd, 1830, in Tarlton, Pickaway

County, Ohio. His parents were Judge Sooy Smith and Ann (Hedges) his wife. Judge Smith was a native of New Jersey and Mrs. Smith of Maryland. This and other interesting facts relating to the family history, we learn from a biographical sketch of General Smith in possession of the Secretary of the WESTERN SOCIETY OF ENGINEERS. This sketch tells of the brave and successful struggle made by young Smith to secure an education. He worked his way through the University at Athens, Ohio. "To pay his tuition and board, and to defray his other expenses, he acted as janitor of the College buildings, doing the laborious work with his own hands, being constantly engaged with his work and studies from five in the morning until nine at night." . . . "he earned the subriquet of *Professor of Dust and Ashes*." But the dust did not cloud his mind nor the ashes humble his spirit, and he graduated with distinction in 1849, having paid all of his bills and accumulated a capital of fifty dollars. The stuff that was in the boy was the stuff that men are made of.

He was appointed to West Point in June, 1849, by Congressman Samuel F. Vinton, who said to him: "I will give you this appointment; now make a man of yourself." He did.

One of us, who knew him well, remembers an anecdote of his West Point life, which he told in a spirited manner. The Superintendent at that time was Robert E. Lee, who in the after years became the idolized leader of the men who fought until their cause was lost. The man who was respected by his foes and beloved by all who admire true greatness of soul and noble manhood. Cadet Smith was doing his turn in the riding hall and the exercise embraced the stunt of riding at full speed, sabre in hand, and taking on the point of the sabre iron rings suspended at intervals around the course. Young Smith's sabre missing the center struck a ring on its circumference and sent it spinning through the air until it was arrested by the forehead of a young lady seated in the spectator's gallery. The unfortunate cadet in deep mortification asked his instructor what he ought to do and he was told that he should write a note to the young lady asking pardon for his awkardness in presenting her a ring. The note was written to the wounded girl, who was a guest of Col. Lee. Later the awkward cadet was invited to dine and meet the young lady, and his treatment by Col. Lee won the cadet's admiration, and though in the fullness of time, when the battle was joined, Lee wore the grey and Smith the blue, that admiration never waned.

In the files of our society is an "official statement of the military service of William Sooy Smith, 2nd Lieutenant United States Army, Colonel 13th Ohio Volunteer Infantry and Brigadier-General of Volunteers." This was prepared by authority of the Secretary of War, T. C. Ainsworth, Adjutant-General.

In terse military language the career of General Smith is traced from July 1st, 1849, through the crucible of the Civil War to the 15th of July, 1864, when, on account of ill health, he resigned and

his resignation was accepted. Concise as is this language it fills nine printed pages.

The military history thus delineated shows the General's claim upon his country's gratitude and justifies the pride of his family and friends in his war record, but it is with the citizen and the engineer that we, as engineers, are now concerned.

In the interval between June 19th, 1854, when he resigned from the Army, and June 26th, 1861, when he was mustered into service as Colonel of the 13th Ohio Volunteer Infantry, he engaged in the practice of Civil Engineering, first on the Illinois Central Railroad, under Colonel Roswell B. Mason, its Chief Engineer.

His service was interrupted by a desperate illness, through which he was nursed by "his affianced wife, Miss Haven, of Buffalo, New York." They were married in 1854, and thereafter, for two years, he taught a select school in Buffalo.

In 1857 he resumed the practice of Civil Engineering, forming a partnership under the firm name of Parkinson and Smith. The firm made the first surveys for the International Bridge across Niagara, and did a large miscellaneous business.

At the time of the breaking out of the Civil War he was engaged in building a bridge across the Savannah River, but when Fort Sumpter was fired upon, he abandoned civil life and drew his sword for the preservation of the Union.

Upon resuming his interrupted engineering career his first work was "the protection built about the Wagoshance Light House at the Western Entrance to the Straits of Mackinac." For the pneumatic caisson sunk there, the first to be sunk in this country and originally designed by him, the General "received an award from the Centennial Exposition (one of the two awards given to American Engineers) and conferred by a jury composed of some of the foremost engineers of the world."

To name all of the engineering enterprises in which he engaged, prior to his accepting the retirement from active service, which advanced age pressed upon him, would indeed make a long list. Therefore, we will only name those engagements which stand out prominently.

Bridge construction and deep foundation work demanded much of his time and many structures spanning the Missouri River are monuments to his constructive ability. The first of these was the bridge at Omaha; then came Leavenworth, and later he built, or helped to build, the bridges at Booneville, Glasgow, Plattsmouth, Sibley and Kansas City. The Glasgow Bridge was the first all-steel bridge ever built.

In other lines of engineering design and execution he had a wide and successful experience.

As a citizen he was active and zealous for the public weal.

As a neighbor he was kindly and companionable.

His interest in the Western Society of Engineers was sincere and helpful and was so much appreciated by his fellow members

that in 1877 he was elected its President, and was his own successor for the two following terms.

His first wife lived only six years after their marriage. Mr. Charles Sooy-Smith was the only offspring of their marriage.

In 1862 General Smith married Miss Anna Durham, daughter of the Hon. V. C. Durham of Bowling Green, Ky. She died without issue, 1882.

In 1884, he was united in marriage to Miss Josephine Hartwell, of St. Catherines, Ontario. Mr. Gerald Campbell Sooy Smith, who survives his father, is the fruit of the last marriage.

The mortal remains of this Veteran Soldier and Engineer now rest in Forest Home Cemetery, near Chicago, where the committal "dust to dust, ashes to ashes," was said over him March 11th, 1916.

Memoir prepared by Mr. Isham Randolph.

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS

Annual Meeting, January 10, 1917.

The Forty-Seventh Annual Meeting of the Society (No. 955) was held Wednesday evening, January 10, 1917, in the Louis XVI room of the Hotel Sherman, Chicago. The meeting was attended by 323 members and guests.

During the dinner music was rendered by the Johnny Hand Orchestra, and a number of special Western Society songs, written by Mr. James N. Hatch, were sung by the assemblage. A number of lantern slides by Mr. N. M. Stineman were also shown, including a series, "It Is Tough To Be the Kid of An Engineer," "Publicity for Engineers," and "Military Unpreparedness."

Retiring President Grant turned over the conduct of the meeting to Toastmaster W. L. Abbott, who kept the speakers in fear and trembling by his thinly-veiled threats to tell the truth about them.

Abstracts of the annual reports were made by Secretary Layfield, after which retiring President Grant gave an interesting summary of the history of the Society since its organization in 1869, and especially its activities during the past year. This address is printed elsewhere in this Journal.

It should be noted here, however, that he announced that Mr. John E. Blunt, who read the first technical paper presented before the Society, Mr. Walter Katte and Mr. Alonzo W. Paige, the three surviving members, who joined the Society in 1869, the year of its formation, and all of whom had attained places of eminence in the engineering world, had been elected as Honorary Members of the Society. He also announced that the Chanute Medals for papers read before the Society in the year 1915 had been awarded to Professor Wilbur M. Wilson, for a paper on "Wind Stresses in the Steel Frames of Office Buildings," and to Col. Curtis McD. Townsend for a paper on "The Currents of Lake Michigan and Their Effect on the Climate of the Neighboring States."

He further announced that the matter of the administration of the honor award, founded by John W. Alvord, has assumed definite shape. This award is to be known as the Washington Award, and is to be made each year to an engineer whose work in some special instance or whose services in general have been noteworthy for their merit in promoting the public good.

President-elect Burt made his inaugural address, in which he asked for the support of the Society in carrying on its work.

On motion of Mr. Isham Randolph, it was voted unanimously to instruct the Secretary to send a letter, expressing the good-will of the Society to Mr. G. A. M. Liljencrantz, who after 39 years of membership in the Society, has recently returned to his native Sweden "to await life's sunset in the land where life dawned upon him."

The other speakers of the evening were Dean F. E. Turneaure, who spoke on "The Engineering School and the Engineer," and Mr. James Keeley, editor of the Chicago Herald, who spoke on "After-War Business Conditions." These addresses are printed elsewhere in this Journal.

A one-act burlesque on the Structural Engineers' License Law of Illinois, entitled, "Why Is a Structure?" the cast of which is printed elsewhere in the Journal, was hilariously received by the audience.

The meeting adjourned at 11:30 P. M.

Meeting No. 956, January 15, 1917.

The meeting was called to order at 7:50 P. M. by Chairman DeBerard of the Hydraulic, Sanitary and Municipal Section, with about 75 members and guests present. This being the annual meeting of the Section, the Chairman

called for nominations for officers of the Section for 1917. The nominations were as follows:

For Chairman.

Dabney H. Maury,
Edmund T. Perkins.

For Vice-Chairman.

Herbert E. Hudson.
John F. Hayford.

For Directors.

William T. Barnes,
Murray Blanchard.

The result of the ballot of these nominations was the election of the following:

Chairman—Dabney H. Maury.

Vice-Chairman—Herbert E. Hudson.

Directors—William T. Barnes, Murray Blanchard.

The retiring Chairman, Mr. DeBerard, also becomes a director, under the rules of the Section.

The Chairman then introduced Mr. T. Chalkley Hatton, Chief Engineer of the Milwaukee Sewage Commission, who read a paper on "Modern Sewage Treatment." This was followed by a paper by Dr. Edward Bartow on "The Purification of Sewage in the Presence of Activated Sludge." Discussion followed by Messrs. Langdon Pearse, Charles H. MacDowell, Dr. Paul Rudnick, Mr. Hatton and Dr. Bartow.

The meeting adjourned at 10:30 P. M.

Meeting No. 957, January 22, 1917.

The meeting which was a joint meeting of the Electrical Section, W. S. E., and the Chicago Section, A. I. E. E., was called to order at 8:00 P. M. by Chairman Keller of the Electrical Section, with about 75 members and guests present. This being the annual meeting of the Electrical Section, the election of officers was in order. In accordance with the rules of the Section, the ticket which had been posted upon the bulletin board was called up for vote, and the Secretary was instructed to cast the ballot for the ticket, which is as follows:

Chairman—E. W. Allen.

Vice-Chairman—Leslie L. Perry.

Member, Executive Committee—C. A. Keller.

Under the rules of the Section, Messrs. E. N. Lake and F. J. Postel continue as members of the Executive Committee. The newly elected Chairman then took charge of the meeting, and introduced Mr. F. A. Lidbury, who presented his paper on "The Nature of the Power Requirements of the Electrochemical Industry." Discussion followed by Messrs. Peter Junkersfeld, H. M. St. John, W. T. Dean, E. J. Fowler, George H. Jones, W. E. Williams, S. Montgomery, Prof. W. C. Bauer, and Mr. Arthur Wright of London.

The meeting adjourned at 11:15 P. M.

Meeting No. 958, January 31, 1917.

A joint meeting of the Electrical Section, W. S. E., with the Chicago Section of the American Institute of Electrical Engineers was called to order at 7:45 P. M. in the rooms of the Western Society of Engineers, with Mr. Taliaferro Milton in the chair, and about 100 members and guests present. Mr. Milton turned the meeting over to Mr. J. G. Wray, who introduced Mr. W. W. Freeman, President of the Union Gas and Electric Co., Cincinnati, who read a paper on the "Relations of Public Utilities and the Public." Dis-

cussion followed by Messrs. E. G. Cowdery, John F. Gilchrist, W. J. Norton, P. Junkersfeld, Lyman E. Cooley, Harold Almert, E. W. Allen, G. C. King, T. Milton, R. F. Schuchardt, R. H. Rice, E. N. Lake, and A. P. Allen.

The meeting adjourned at 10:20 P. M.

E. N. Layfield,
Secretary.

SECRETARY'S REPORT, JANUARY 10, 1917.

Board of Direction, Western Society of Engineers.

Gentlemen:—I respectfully present herewith the annual report of the proceedings of the Society for the year 1916.

The membership of the different grades and of the Society as a whole, December 31, 1916, is shown in the following table:

Honorary Members	1
Members	746
Associate Members	239
Junior Members	122
Affiliated Members	36
Student Members	61
Total	1,205

Death has claimed the following members during the year:

Grenville M. Dodge, died January 3, 1916.
E. D. Miller, died February 4, 1916.
William Sooy Smith, died March 4, 1916.
Lightner Henderson, died March 17, 1916.
L. P. Morehouse, died March 18, 1916.
Frank H. Pond, died April 12, 1916.
E. L. Corthell, died May 16, 1916.
James V. Rockwell, died May 24, 1916.
F. S. Brown, died May 31, 1916.
Charles Sooysmith, died June 1, 1916.
C. H. Cartlidge, died June 14, 1916.
D. J. Whittemore, died July 16, 1916.
W. R. Patterson, died July 19, 1916.
Virgil G. Bogue, died October 15, 1916.
Charles W. Hotchkiss, died October 28, 1916.
E. T. Hendee, died November 12, 1916.

Thirty-one meetings were held during the year as follows:

Monday, January 24 (No. 925). Joint meeting of the Electrical Section with Chicago Section A. I. E. E., being the annual meeting of the Electrical Section. "The Modern Seven-League Boots," by Mr. H. N. Foster.

Monday, February 7 (No. 926). Meeting of the Hydraulic, Sanitary and Municipal Section. "Intensive Street Cleaning Methods," by Mr. Richard T. Fox.

Monday, February 14 (No. 927). Meeting of the Bridge and Structural Section. "Stresses in Webs and I-Beams," by Prof. Herbert F. Moore.

Monday, February 21 (No. 928). Ladies' night, with an address by Judge Charles S. Cutting on "George Washington."

Monday, February 28 (929). Joint meeting of the Electrical Section with the Chicago Section of the A. I. E. E., and the Chicago Section of the Illuminating Engineering Society. The general subject for the evening was "Street Illumination." The following papers were presented: "Recent Street Lighting Problems and Developments," by Mr. J. R. Cravath; "Some Experiences and Tests in Connection with Chicago Street Lighting," by Mr. A. C. King; "Street Lighting Plans of Milwaukee," by Mr. F. A. Vaughn.

Monday, March 6 (No. 930). Regular meeting. "Power Station Buildings," by Mr. James N. Hatch.

Monday, March 13 (No. 931). Meeting of the Bridge and Structural Section. "Large Modern Lock Gates," by Mr. Malcolm Elliott.

Monday, March 20th (No. 932). Informal talk by Prof. John F. Hayford on the Panama Canal land slides.

Monday, March 27th (No. 933). Joint meeting of the Electrical Section with the Chicago Section of the A. I. E. E. and the Chicago Section of the Electrical Vehicle Association. The general subject for the evening was "Electrical Vehicles." The following papers were presented: "Automobile Motor Characteristics," by Mr. F. A. Putt; "Accomplishments of the Electric Passenger Car," by Mr. Gail Reed; "The Electrical Commercial Vehicle," by Mr. W. J. McDowell; "Storage Battery Industrial Trucks and Tractors," by Mr. W. F. Hebard.

Monday, April 3rd (No. 934). "The First Year's Operation of the Locks of the Panama Canal," by Mr. F. C. Clark and Mr. R. H. Whitehead. The paper was read by Mr. S. H. Grauten.

Monday, April 17th (No. 935). Meeting of the Hydraulic, Sanitary and Municipal Section. "The Construction of the Wilson Avenue Water Tunnel, Chicago," by Mr. H. W. Clausen.

Monday, April 24th (No. 936). Joint meeting of the Electrical Section with the Chicago Section A. I. E. E. The general subject for the evening was "Central Stations in Cities of Less Than 50,000 Inhabitants"; the papers being as follows: "Thoughts in Connection With the Electrical System of Small Central Stations," by Mr. Albert J. Goedjen; "Station Management," by Mr. Adam Gschwindt; "Distribution of Electrical Energy With Particular Reference to Small Communities," by Mr. A. Hardgrave; "The City Manager," by Mr. R. L. Fitzgerald.

Monday, May 1st (No. 937). "Fortification," by Capt. Henry B. Sauerman. The paper was read by Lieutenant Guilfoil.

Monday, May 8th (No. 938). Meeting of the Bridge and Structural Section. "The Operating Machinery of the Willamette River Drawbridge, Near Portland, Oregon," by Mr. Byron B. Carter.

Monday, May 15th (No. 939). "The City Manager—A New Opportunity for Engineers," by Mr. Gaylord C. Cummin.

Monday, June 5th (No. 940). "Public Service Opportunity and Preparedness," by Mr. J. L. Jacobs.

Monday, June 12th (No. 941). Meeting of the Bridge and Structural Section. "Comparative Designs of Office Buildings," by Mr. Fred Ruchti.

Monday, September 11th (No. 942). Smoker. Informal talk by Mr. John K. Melton on the lower Mississippi River in time of flood.

Monday, September 25th (No. 943). Meeting of the Hydraulic Sanitary and Municipal Section. "Investigation of Flood Flow of Wisconsin River at Merrill, Wis., July 23-24, 1912," by Mr. Clinton B. Stewart.

Monday, October 2nd (No. 944). "The Engineer and Public Service," by Prof. Clarence T. Johnston. The paper was read by the secretary.

Monday, October 9th (No. 945). Meeting of the Bridge and Structural Section. "Things We Do Not Know About Structural Engineering," by Prof. Wilbur M. Wilson.

Monday, October 16th (No. 946). Meeting of the Hydraulic Sanitary and Municipal Section. "A Comparison of the Activated Sludge and the Imhoff Tank-Trickling Filter Processes of Sewage Treatment," by Mr. Harrison P. Eddy.

Wednesday, October 25th (No. 947). Joint meeting of the Electrical Section with the Chicago Section A. I. E. E. "The Effect of the European War on American Industries," by Dr. Charles P. Steinmetz.

Monday, November 6th (No. 948). "The Construction of a Narrow Gauge Railroad in the Republic of Panama," by Mr. Aaron S. Zinn.

Monday, November 13th (No. 949). Meeting of the Bridge and Structural Section. "Timber Decay and Its Growing Importance to the Engineer and Architect," by Prof. C. J. Humphrey.

Monday, November 20th (No. 950). Meeting of the Hydraulic, Sanitary and Municipal Section. "Importance of the Relation of Solid Surfaces and

Liquid Films in Some Types of Engineering Construction," by Dr. Clifford Richardson.

Monday, November 27th (No. 951). Joint meeting of the Electrical Section with the Chicago Section of the I. A. E. E. "Temperature Distributions in Electrical Machinery," by Mr. B. G. Lamme, and "Rational Temperature Guarantees for Large Alternating Current Generators," by Mr. F. D. Newbury.

Monday, December 4th (No. 952). "Industrial Democracy With Particular Reference to the Relations Between Capital and Labor," by Mr. George Weston.

Monday, December 11th (No. 953). Meeting of the Bridge and Structural Section. "Addition to the Union League Club Building," by Mr. F. E. Brown.

Monday, December 18th (No. 954). Meeting of the Hydraulic, Sanitary and Municipal Section. "Types of Roads for a County Bond Issue," by Mr. Walter W. Marr.

Respectfully submitted,
E. N. Layfield, *Secretary.*

REPORT OF CHANUTE MEDAL AWARDS.

Mr. B. E. Grant, President, Western Society of Engineers,
1735 Monadnock Block, Chicago, Ill.

Dear Sir:—The undersigned were informed by letter, dated May 9, 1916, of their appointment as a committee "to make the award of the Chanute medals, for papers presented to this Society during the year 1915."

We unanimously recommend to the Board of Direction that two Chanute medals, and only two, be awarded for papers presented in 1915, namely, to Col. Curtis McD. Townsend for a paper in general engineering entitled "The Currents of Lake Michigan and Their Influence on the Climate of the Neighboring States," and to Prof. Wilbur M. Wilson for a paper in civil engineering, entitled "Wind Stresses in the Steel Frames of Office Buildings."

Respectfully,
(Signed) John F. Hayford,
Ralph H. Rice,
I. F. Stern.

REPORT OF JUDGES OF ELECTION, WESTERN SOCIETY OF ENGINEERS, JANUARY 5, 1917.

The undersigned judges of election, having canvassed the ballots cast for officers of the Western Society of Engineers for the year 1917, have the honor to report as follows:

Total number of votes cast	376
Total number of ballots rejected as irregular	6
Total number rejected as not qualified to vote on account of non-payment of dues	3
Total number of ballots counted	367
Number of votes cast for president:	
H. J. Burt	264
C. F. W. Felt	93
Number of votes cast for first vice-president:	
P. L. Battey	125
D. W. Roper	223
Number of votes cast for second vice-president:	
James N. Hatch	244
Edmund T. Perkins	113
Number of votes cast for third vice-president:	
W. W. DeBerard	180
E. T. Howson	169

Number of votes cast for treasurer:

C. R. Dart 351

Number of votes cast for trustees for three years:

O. F. Dalstrom 227

G. C. D. Lenth 117

Respectfully submitted,

TALIAFERRO MILTON,
A. S. ZINN,
FRANK H. BERNHARD,
Judges of Election.

PROCEEDINGS OF ANNUAL MEETING AND DINNER.

January 10, 1917.

Retiring President Grant: Last November an engineer ran for office in the State of Illinois, a rather unusual event. The engineers voted for him, and he had a million and some odd votes. He was elected. A short time ago our committee held an election and the same man was elected again. You know who it is—Mr. Abbott—and he is going to try to keep you in order.

Toastmaster Abbott: A few weeks ago I chanced to meet your Secretary and retiring President at luncheon—at the Congress hotel and they suggested to me that I act as toastmaster this evening at your Annual Meeting. I offered the customary excuses, and suggested that they look further for a real toastmaster; and after thinking it over they thought that that was good advice. So they dropped the subject, and I heard no more about it for another week or so, when I chanced to meet them again at luncheon. This time I believe it was at the Blackstone. (Laughter.) And they renewed their suggestion. I reminded them of my previous recommendation and asked them why they had not acted upon it. They said they had taken it seriously and had looked everywhere for a toastmaster, and, much as they regretted it, they were forced to fall back on me. Well, of course, I was flattered by the nice way they put it, and as I thought that Mr. Grant was about to ask the waiter for my luncheon check, I accepted. (Laughter.)

Then he proceeded to tell me what the duties of a toastmaster are, and said, "A toastmaster should partake of the nature of a drum-major, and also of the nature of a tombstone." I could not guess the riddle and asked him what the answer was. He said, "You have seen the drum-major, the real, old-fashioned kind with the huge bear-skin shako and silver-headed baton, going ahead of a body of musicians, each of whom was blowing his horn to beat the band. And as often as you have seen that," he said, "you have noticed that although the drum-major was not one of the performers, strictly speaking, yet by his imposing presence and by the dexterity with which he juggled his baton he did much to reconcile the bystanders to the brazen blare which followed." (Laughter and applause.) "I see," said I, "I am to flash my glittering baton so fascinatingly over that meeting that, in spite of what may follow—ah, yes, it is very simple." (Laughter.) "But how about the tombstone stuff?" "That," said he, "is even more simple. To illustrate, there used to be a beautiful custom, which now, unfortunately, is usually observed in the breach, but a parallel of which might well be introduced into our annual meetings and made a prominent feature thereof. I refer," he said, "to the old custom of engraving upon the tombstone of some dear departed a few words extolling his virtues and achievements. And what did it matter if the available material referring to said virtues and achievements were not sufficient to fill up the space on the stone allotted for the inscription? What did it matter if the engraver, to fill out the space, should draw upon both imagination and fiction for additional virtues and achievements? No one was harmed, and the departed, in looking down—or up, as the case may be—at the tombstone (laughter) would be pleased, and in course of time would come to believe it even himself." He said, "You get

the idea?" I thought I did, for I understood that as the price of my appointment I was expected to lie like an epitaph about some of these outgoing officers. (Laughter and applause.) I really had no compunctions about lying about Brother Grant; and, in fact, after he arose from the table without saying anything to the waiter about my luncheon check, I could even tell the truth about him. I may do so yet. (Laughter.) I wish to say, however, in all fairness to him that that brazen blare talk which he gave me was before he had received the acceptance of the distinguished gentlemen who are to address you this vening, and that I later was called up and some of my previous instructions were countermanded, and I therefore this evening will merely occupy the place of the obsequious and deferential door man who pompously introduces the distinguished guests as they arrive.

With these brief remarks we may proceed with our program, and I bespeak for the speakers, as they come on, the same hearty reception with which your toastmaster was greeted. (Laughter and applause.)

Preliminary there are a few business matters to be disposed of, and the first one will be the Secretary's report for the year. I might say a word about the Secretary. He at one time was connected with the Grand Central Passenger Station here in the city, and was a party to the perpetration upon navigation of that iniquity known as the Taylor Street railroad bridge. He built it so close to the water that you could not row a skiff under it, and so high in the air that you could not fly a hydroplane over it, and with so many braces that you could not crawl through it. His idea of keeping the road open was to keep the bridge closed (laughter), and the facilities for keeping it closed were of the best. (Laughter.) I had some experience in attempting to navigate the river lengthwise, and navigation was usually fair until it struck that bridge. I have had to go ashore there to climb a 60-foot ladder, wake up the bridge-tender and ask him to have a cigar on me and please open the bridge. (Laughter.)

Such things, however, sometimes compensate themselves, and Mr. Layfield, who, as I said, was a party to this iniquity, was once hoist by his own petard. He was out on the end of the leaf one day when something awoke the bridge-tender and caused him to lift the bridge. The atonement might have been complete, but Layfield hung for dear life and did not fall off. Secretary Layfield, we will now hear the secretary's report.

(Abstract of Annual Reports read by Secretary.)

The retiring President each year has only one principal opportunity to distinguish himself, and it is for that purpose that so many of us have gathered here tonight, to celebrate his exit. (Laughter.)

Mr. Grant is, in point of membership, one of the very old members of the society, having been a member, I believe, for nearly thirty years. I shall always be grateful to him for my introduction into the political life of the society. It was due to his influence that I once secured the appointment to the important position of member of the Membership Committee (laughter), of which Mr. Grant himself was chairman.

I had thought of telling some of the things which occurred during those meetings, but lack of time, and perhaps consideration for some of those who are here, induces me to forego. During the year 1903 there was a great increase in the membership of the society. It was remarked at the time, and frequntly since, that the quality of the membership accepted that year was away below par. Now, there are many seated here tonight, whose names and faces are familiar to us all, whom I might point out as having gotten in at that time (laughter), and to you gentlemen I will freely admit that it was due to Mr. Grant's intercession in your behalf and to his steam-roller methods in committee that you are here. However, we need say no more about it. (Laughter.)

Now that everything is prepared for the supreme event of the evening, we will listen to the address of the retiring President. (Applause.)

ADDRESS OF RETIRING PRESIDENT BERTRAND E. GRANT.

The first thing that I have to say tonight no doubt will please every one.

My swan song is very short. The committee intimated that I should occupy somewhat less than an hour, so I compromised with them on fifty-nine minutes. (Laughter.)

This meeting tonight is marked on our program as the Forty-seventh Annual Meeting of the Society. As a matter of fact the Society is somewhat older than that. It was organized in May, 1869, and while none of the twelve members who organized the Society at that time are still in the land of the living, we have three members who were elected during the first year of the Society's life. They are Mr. John E. Blunt, who was elected at the second meeting of the Society, and who read the first paper ever presented to the Society (applause); Walter Katte, who came in at the third meeting of the Society, held in July, '69; Alonzo W. Paige, who came in at the eighth meeting, held in December. And he set a precedent which has not been generally followed, but is a very good example. At the first meeting following his election, he read a paper before the Society, and that was the second paper presented to the Society. The Board of Direction met a few days ago and elected to honorary membership the three distinguished men I have just mentioned. (Applause.) They have been members of the Society for forty-seven years.

And in this connection I might mention that there are seven members whose term exceeds forty years. There are some five hundred who have been members for ten years or more.

The past year has seen the completion of the twenty-first volume of our Journal. The bound volumes of the Journal now make something of a library in themselves, and are something of which we should all be proud.

Early in the past year a number was issued as an index to the twenty volumes preceding. This work was gotten out by the Secretary and his assistants, and is an exceedingly valuable number of the Journal. The Journal is one of our most highly prized assets, and is a means of bringing to the Society as a matter of exchange a great many of the best technical periodicals published. You will find a list of them in the year book. There are some eighty-one titles in the foreign list, and two hundred and thirty odd in the domestic list, so that we get over three hundred technical publications in exchange for our Journal. Those are not all on display, on account of the room required, but they are listed so that they can be readily found.

Our library now contains more than ten thousand volumes. And it is growing each year. It has already encroached on our meeting room, and a problem which will soon be up to the officers of the Society is to find space for the library.

Your incoming and outgoing Presidents have generally felt it to be their duty to tell you that we need more members. Undoubtedly we do, and probably always shall. It is a question in my mind as to whether the Western Society of Engineers has always taken the right attitude towards this increase of membership. One view of it is that the society is a highly dignified, scientific Society, of such eminent standing that an engineer must come to it of his own initiative, presenting a record of his past achievements, and solicit admission. The other view is that the society should actually endeavor to seek out men in our profession who ought to be members and urge them to join and add their strength and influence to a growing organization for the good of their brother engineers in particular and the public in general. The first view, judging by the past history of other societies as well as our own, will give an organization of slow growth and a field of usefulness limited by the activities of a comparatively small percentage of the members of the profession. The second view should tend to interest and bring into the fold a large number of men who either are not affiliated with any society or are putting their time and energy and money into the formation of a new society which must go through the inefficient and expensive period of childhood before reaching maturity and a maximum of usefulness. The second view of the matter is, I think, more in harmony with the spirit of our constitution which intends to bring into one fold engineers of all classes—civil, mechan-

ical, electrical, chemical, and mining. The interests of some of these various divisions are now being successfully cared for by means of sections. The electrical section now co-operates with the American Institute of Electrical Engineers, with material advantages for both societies. Similar working arrangements with other societies are very desirable.

Last April there was held in the rooms of the Western Society of Engineers, under the auspices of a volunteer committee, a conference on co-operation. Five sessions were held, and were attended by representatives of some twenty-five societies. A wide diversity of opinion was expressed at the meetings, and the net result apparently was the appointment of a committee to report on a plan for co-operation among engineering societies, and the addition of one more to the already long list of engineering organizations. And it is perhaps the wide diversity of opinion on the subject which justifies its continued discussion.

That engineers can co-operate successfully was proven last summer by a remarkable demonstration. A volunteer committee, of which Mr. Perkins was chairman, was formed by representatives of more than a dozen societies, with the purpose of having an engineering division in the Preparedness Parade. Money was collected, and a short campaign was made, with great success. More than two thousand men turned out in the engineers' division on June 3rd. The members of the Western Society were leaders in this movement. The parade in itself was a wonderful event, but it was only one manifestation of a widespread agitation concerning one of the most important questions before the American public today.

The president of the Chicago Association of Commerce recently called a conference at the Union League Club of representatives of many of the societies that took part in the parade, for the purpose of formulating and promoting some definite plan of action on this question. There is another meeting of the same kind held there tonight, at which this Society, of course, is not represented.

Probably the members of no society rank higher in loyalty and the ability to give valuable service in this matter than the members of the Western Society of Engineers, and we should take advantage of the opportunity. It is interesting to recall at this time that the early success of the aeroplane and of the submarine are largely due to work of members of our society, the name of Chanute being prominently connected with the one, and of Saltar with the other. While possibly some names are better known to the general public than Chaunte's, the leaders in the work today recognize Chanute as the father of aviation.

At the request of President Wilson, early in the past year, five national engineering societies undertook the work of assisting the Naval Consulting Board in collecting data concerning all industrial plants producing anything that might be classed as munitions in time of war. The committee appointed by those societies to do the work in the State of Illinois, requested the help of the Western Society of Engineers. Our Board of Direction gladly complied. And the rooms of the Society became the headquarters for the Illinois directors. Mr. Layfield, our Secretary, gave much of his time for several months to this work. The fact that the five men placed on the Illinois committee, representing five different branches or engineering, were all members of the Western Society of Engineers, is a splendid illustration of the broadness and inclusiveness of our membership.

One of the sad events of the past year was the death of Mr. Cartlidge, who sat at this table one year ago as our first Vice-President. Mr. Cartlidge was a man whose character and ability were held in the highest esteem by the officers and members of the Society, and the engineering profession generally. He was chief engineer of the Paducah & Illinois Railroad Company, and had charge of both the design and the construction of the great bridge across the Ohio river at Metropolis. After his death the Board of Direction suggested to the president of the C. B. & Q. Railroad that it would be an appropriate thing for the company to place a tablet on the Metropolis bridge commemorating Mr. Cartilage's connection with that great structure.

The suggestion was favorably received, and the tablet will be placed by the company.

During the past year death has claimed an unusually large number of our prominent members. Our loss has included two past presidents, E. L. Corthell and William Sooy Smith; and three Honorary Members, General Grenville M. Dodge, D. J. Whittemore, and L. P. Morehouse, who was the first Secretary of this Society.

One year ago, Past President Alvord gave to the Society a fund for the establishment of an honor award. In his letter of transmittal, he said:

"I desire to see established by the Western Society of Engineers an Honor Award, by medal or other token, to be annually presented to that engineer whose particular work in some special instance or whose services in general have been noteworthy for their merit in promoting the public good."

Early in the year a committee, composed of William B. Jackson, C. F. Loweth, and C. D. Hill, was appointed to report on the best method of administering this award. This committee gave much time and study to the matter, and has made a report which has been adopted by the Board of Direction. Briefly summarized, it provides that the title of the award shall be "The Washington Award, founded by John W. Alvord, and administered by the Western Society of Engineers." That the token of the award shall be a bronze medal, or other work of art, and shall be accompanied by a certificate stating the nature of the services for which the award is made.

That the commission of award shall be guided by the spirit of the letter of the founder, and not by specific rules.

That the commission of award shall consist of nine members of the Western Society of Engineers, and two members from each of the following societies:

The American Society of Mechanical Engineers;
The American Institute of Electrical Engineers;
The American Institute of Mining Engineers, and
The American Society of Civil Engineers.

The commission is to place in an eligible list the names of all engineers whom it considers worthy of the award, and is to finally select as the recipient only an engineer who has been under consideration for at least one year, except in the case of the first recipient. A meeting of the Society is to be held on the third Monday of February in each year at which time the formal presentation is to be made.

The preliminary negotiations indicate that the four national societies will co-operate in making this award. The Board of Direction and the president of the Western Society of Engineers have appointed the following members as the first commission of award:

William B. Jackson.
F. H. Newell.
W. S. Lacher.
C. F. Loweth.
W. L. Abbott.
Isham Randolph.
C. D. Hill.
W. H. Bixby.
H. S. Crocker.

In the list of our Past-Presidents you will find the names of many engineers who have had national fame, and not a few who have been known internationally. One of the most highly honored names in the list is that of Chanute. The appreciation of his services continues to grow as the years go on. While he was not one of the organizers of this Society, he was one of the first elected to membership in '69. While President he gave the Society a fund for medals to be awarded annually for the best papers presented before the Society. The Chanute medals have been awarded each year since 1901. The original design of the medal was employed until the presentation for the papers of 1911, for which a new design was adopted and a great

improvement was made in both the design and the execution of the medal. One side of the medal bears the profile of Mr. Chanute, and the other side the name of the recipient and date in relief, as the result of a special die made for each medal. The awards for the papers presented during 1915 are to Colonel Curtis McD. Townsend, for his paper on The Currents of Lake Michigan and Their Effect on the Climate of the Neighboring States (applause); and to Professor Wilbur M. Wilson, for his paper on Wind Stresses in the Steel Frames of Office Buildings (applause).

I am going to ask Colonel Townsend and Professor Wilson to step forward and receive the medals and the certificates. (Applause and cheers as the medals and certificates were presented.)

The election held last week—you have been getting the returns all evening—resulted as follows:

President—Henry J. Burt.
First Vice-President—Denney W. Roper.
Second Vice-President—James N. Hatch.
Third Vice-President—W. W. DeBerard.
Treasurer—Carlton R. Dart.
Trustee—O. F. Dalstrom.

And notwithstanding some of the Toastmaster's remarks, we never had a finer lot of officers. (Applause.)

I have only one more thing to add to my short song. I cannot leave the place without saying that I appreciate the work of the officers of the past year, of the committees which have been active, and of the members who have lent their enthusiastic support to all the activities of the Society. (Applause.)

Isham Randolph, M. W. S. E.: Mr. Toastmaster.

Toastmaster Abbott: Mr. Randolph.

Mr. Randolph: I desire to present the following resolution:

Whereas, one of our oldest and most honored members has recently passed away—not from earth, but from our midst to await life's sunset in the land where life dawned upon him—and it is most fitting that to him, through its Secretary, this Society should send a letter expressing its good will for one who has been an honored member for thirty-nine years and who year after year, for the most of that period, has by his genial presence and social gifts helped to make these reunions of ours around the festive board joyous occasions—I hardly need pronounce the name to which this description applies, for we old fellows know, and you young fellows guess that it is G. A. M. Liljencrantz (applause), who after forty-three years service as civil assistant engineer in the Chicago office of the United States Engineer Department, has gone back to his native Sweden to live the rest of his allotted span among his own people.

I, therefore, move that the secretary be instructed to carry out the spirit of this suggestion.

(The motion was duly seconded.)

Toastmaster Abbott: You have heard the motion. All those in favor say "aye." Contrary, "no." The motion is adopted and the secretary will note the instruction. I very heartily concur in the sentiment of the resolution which has just been offered. Mr. Liljencrantz and I were intimate friends for a number of years, and I owe him a very great debt of gratitude. It so happened that Mr. Liljecrantz was nominated for president of the Society at the same time that your speaker was, and owing to Mr. Liljencrantz's great consideration in withdrawing from the race, I attained that high office myself. (Laughter.)

Whenever I see the award of these Chanute medals made, I feel that the Society is greatly honoring itself in conferring them, and I think that it might go a step further and put all of the holders of these medals on the list of honorary membership. I speak very feelingly in this matter, holding one of the medals myself. (Laughter.)

Off with the old love and on with the new! Your retiring president intimated that I had said something derogatory to the new officers. Now, if

he will read the newspaper account of my address in the morning (laughte), he will see that I did not speak slightingly of the new members or the new officeholders. On the contrary, I am glad to welcome them. The Society faces the coming year with hope—with some hope (laughter). It is needless to remind them that up until now—I repeat, until now (laughter)—the Society has had fairly efficient officers, with an occasional lapse, of course. But the standard has been set so high that we might be pardoned for looking into the future with some little foreboding.

I am not a little surprised that so young a member as our new President should presume to aspire to that high office a second time after the good drubbing which followed his first attempt (laughter). I believe that after the first five or six years of the existence of the Society it had no President who was such a young member as the President-elect is. He certainly managed his campaign skillfully (laughter), as was expected by those who were on the committee which put through, and put over, the structural engineers' bill. Mr. Burt was the chairman of that committee, and the methods he used in securing its passage would make valuable "copy" for the front page of the Herald. (Laughter.)

Gentlemen, I take great pleasure in presenting your new President, Mr. Burt.

ADDRESS OF PRESIDENT-ELECT HENRY J. BURT.

I am somewhat abashed to find myself elected to the presidency of the Western Society of Engineers. It is only commonplace to say that I am sensible to the honor conferred and the confidence reposed in me by this selection. That it is a high honor is evident when one considers the standing of this Society in its relation to our profession, and my selection must indicate your confidence, else you would be remiss in your duty to the Society in entrusting the administration of its affairs in my hands.

But I cannot interpret your action as a desire to honor me, for I have done nothing to deserve this distinction, my work in the Society having been no more than should be expected from any one of its members, certainly much less than many have done. But rather, I interpret that I am selected to do certain service, so I must, if possible, earn the honor after it has been conferred. Therefore, I accept the presidency with the understanding that it is a job as well as a position, and I understand the work pertaining to the job with the determination to do it to the best of my ability.

I am skilled enough in politics to realize the dangers in making promises, and I make no promises for specific performance. Then if anything worth while is done during the coming year, I can brag about it at the next annual meeting. That will be much pleasanter than explaining why certain promises were not fulfilled. Of course, if nothing is accomplished it will be the fault of the Secretary and the Board of Direction.

While no policies are to be announced, the list of officers in charge of your affairs for the coming year assures a constructive program. Certainly they will not be satisfied to see the Society run along its way propelled only by the momentum acquired during the past year and preceding years, but will endeavor to see it grow in size, in strength, in influence, and most important of all, in value to its members.

The past few years probably have been the best in its history, so it will be no small task to make the coming year a better one. The hearty cooperation of all its officers will be necessary, and there is no doubt that every one of them will do his part. But, more important than anything else, there must be support from the membership by presenting technical papers and discussions at the meetings, by giving proper publicity to the Society's activities and by bringing into membership those whose qualifications entitle them to that honor.

If the dinner you have eaten, the cigars you are smoking, or the speeches of the evening prove too heavy for your digestion so that you awake tonight, please spend those wakeful minutes in planning something that you can do for the good of the Society.

Do not hesitate to give advice. It will be welcomed, for I am not too old or too set in my ways to receive and accept it. In fact, I have already solicited and am using such assistance. By a member of the committee of arrangements, I was counseled to make this speech short; from the Secretary I learned what I must say, and by the retiring President I have been advised of some of the problems ahead of me.

Gentlemen, I thank you most sincerely for the privilege of serving as your President and trust that I shall be able to render that service to your satisfaction.

Toastmaster Abbott: Our next number on the program will be an address from a distinguished engineer and educator, one who is well known to all the fraternity, particularly in the central west. He is so well known that I hesitate to attempt any introduction. I will say that although he is connected with a foreign educational institution—foreign to this State—that he is not necessarily to be considered in any sense a rival to the greater institution within our own borders. Indeed, we are proud, and we trust he is proud, that he bears a doctor's title granted by the University of Illinois. It is true that this honor was confirmed upon him before I had anything to do with the direction of the affairs of the institution. (Laughter.) It is also true that since that was granted, that institution has tightened up in a great measure (laughter) on the conferring of those degrees (laughter), but nevertheless we are all glad that he got in in time and got his degree. (Laughter.)

I take great pleasure in introducing Dean Turneaure.

(Dean Turneaure's address is printed on page 1.)

Toastmaster Abbott: There are a great many things which might be said in reference to the next speaker, and I feel impelled to say a great many things about him—some of them true; but owing to the lateness of the hour I will forego most of this chaff. I will say, as you all know, that he is a distinguished editor of a great newspaper, and his hand is on the pulse of the affairs of this great city. I might also go a little further, perhaps, and say that his grasp is on the wrist of a good many affairs of this city at the present time.

He has been abroad and has personally seen many stirring events of the great war. Accounts of some of these have appeared in the newspapers, and others, I believe, are to appear, and we will hear from him tonight more regarding them.

I will just trespass on your time a moment to say it was my fortune to be in France at the beginning of the war. The first thing that impressed me after landing was that the people couldn't understand English (laughter); the next thing that impressed me was that they couldn't understand French very well. (Laughter.)

Before going abroad I had learned from my friend, Captain Hunt, something about the Parisian underworld. (Laughter.) He didn't tell me just what it is nor where it is, but said I ought to see it, and so when I got to Paris I innocently went to a subway station to take a train to the underworld. (Laughter.) I supposed that was the way, but when I got to the station I found a rope stretched across the entrance, on which was hung a notice reading: "Fermé parce que les employées sont partis pour le frontiere," which I understand was the French way of saying that the underworld is closed on Sundays. (Laughter.)

The next day we went to the Eifel Tower, where we saw a number of guards. One of them, a sergeant, with a gun and bayonet and a harsh voice, which belied the merry twinkle in his eye, approached us, and, drawing a forefinger across his throat, said, "Est-ce que vous etes des Allemands?" I don't know what it meant, but I took it for an unfriendly act. (Laughter.) And we moved on.

We started to get out of France, and by diligence and by crowding in at the head of the line and by the use of some coin we got out in a week, and finally when we got to the Channel there had our last experience of the

horrors of war, when the genial hotel-keeper discounted our British gold 20 per cent. (Laughter.)

Mr. Kelly—Mr. Keeley (laughter) has been (laughter and applause)—don't applaud the speaker until I introduce him (laughter)—is fresh from those scenes and doubtless had many more stirring adventures than I did. He will speak to us regarding some thoughts about after-war business conditions—the war after the war. (Applause.)

SOME THOUGHTS ABOUT AFTER-WAR BUSINESS CONDITIONS.

JAMES KEELEY.

Now, Gentlemen—Mr. Toastmaster and Gentlemen:

Now, the little document I have here is not quite so formidable as it looks. It contains some information that I have recently received from the other side about what American business is going to confront when the war is over. If you want to listen to that, well and good. If you don't, I will tell you some stories about the war.

Gentlemen, when the war is over another war is going to start. The engineers of Europe are running the war today. That is the fact. And when peace comes and the peace war starts, the engineers are going to run that war. They are in the saddle in England today. They are being utilized by the British government, by capital, by labor, preparing their plans for this war after the war. The same conditions exist in France. The same conditions exist in Germany. You gentlemen will have to fight the battle for America, because it is going to be a war of engineers and a war of science.

When I was in England I made it a point to ask every man of any importance—and in that category I place not only cabinet ministers, business men and financiers, but the laboring men and the union leaders—to ask each one of those men if there would be any concerted drive against neutral countries by the allied countries in accordance with the Declaration of Paris, in a business way, when the war was over. I wanted an interpretation of the Declaration of Paris. I asked if it was directed solely at the Central Powers, or if in its application it might apply to neutral nations. I may say that the reply I received was it had absolutely no application as far as the United States of America was concerned, that the allied or entente powers were simply erecting their business fences against the enemy powers after the war was over. I asked Lloyd George, and he said this: "Any man who thinks that England, or Great Britain, with its coast configuration, with its open mouths, the harbors and the estuaries, with its isolation as an island—any man who would think that Great Britain after the war was over could get along without America was a d—n fool."

The same point of view was expressed by Mr. Runciman, President of the Board of Trade; Mr. McKenna, Viscount Grey—all the big men, the editors, the labor leaders. They said, however, that England was going to try to secure what it once held—world trade supremacy. They realized, they admitted, that in the last thirty years English trade had been declining. Inefficient methods had crept into British institutions. I think they listed sixty inventions which they claimed were the product of British brains, had been taken by American and German scientists and engineers and developed to the advantage of America and Germany, and to the marked disadvantage of England.

Now, that day is over. England, commercially, is awake. England, as a manufacturing nation, is awake. We have been importing gold from England. They have been importing brains from us. They have taken our efficiency engineers. You gentlemen doubtless know of scores of American engineers who have gone over there. And they have shed the light of efficiency and scientific management on the English manufacturing problems. They have swept away the clouds. They have swept out the cobwebs. And today England, as a manufacturing nation, is awake, alert, efficient, and is going to be no mean competitor of America when the war ends.

The government is awake. It is acting with business. It is acting with labor. It is looking ahead. It is extending a helping hand in every direction. It has pledged to labor, that after the war is over it will see that labor suffers no disadvantage from the increased production which labor has come to realize must occur if England is to maintain its place as a manufacturing and a goods-selling nation. England has started co-operative buying. The English government has started co-operative buying of basic materials. The Allies have in their various countries a number of minerals and products that are not produced in Germany. What have they done? They have declared that after the war they will not sell those products to Germany, to Austria, to Bulgaria—to the enemy nations. Most of the Australian zinc went to Germany. The English government has made a contract with the Australian government to purchase one million tons of zinc in the next ten years, and the Australian government has gone on record that it will never sell another ounce to Germany again. Of course it will ultimately. Of course this Declaration of Paris will remain in effect for only a few years. The Declaration of Paris has the effect of binding these nations together during the war. And it will have some effect at the conclusion of the war. But that it will be as everlasting as the hills, no one suspects and no one believes. And I really think no one hopes that it will.

The most recent, significant development of the British drive for trade after the war came to my notice two days ago. And this developed since I left England, and I left there—oh, less than five weeks ago. Cities such as Sheffield, Manchester and Birmingham are working on what they call municipal encouragement of industry. Translated, that means that Sheffield, for instance, is going as a municipality to stand back of the industries of that town. This is in addition to governmental aid, in addition to protection—for that will be a part of British policy when this war is over. Sheffield is going to get behind its steel. It is going to be behind the manufactures of Sheffield and is going to help them in their fight for world trade. The same scheme is in operation, or will be in operation, in Manchester and in Birmingham. And even the Five Towns—Wales' Five Towns—have combined, and since the war started they have so developed their pottery industry that today they think that when the war is over they may be able to compete with their German competitors. Whether they will or not I don't know, but you can see the importance of that. You can see the importance of a community getting behind a product that is produced in its civic circle.

As I said a moment ago, labor and capital are organized, and they are going to work together. And that means that efficiency methods will be introduced, with the consent of the workers. And that means also increased product. Work on the problem of industrial reconstruction after the war has gone further in England than in any other branch because the relations between capital and labor are considered absolutely the essential thing. The big idea that is being hammered in every day is that after the war neither labor nor capital can work for itslf, but both must work for the state. And the government proposes to make good on this by new solicitude for both industry and commerce.

Officially, steps already have been taken to put the laboring classes behind the enterprise of world trade. I want to read a little bit of this because it is official. In the Reconstruction Commission there is a sub-commission on the redemption of pledges made to labor in connection with the suspension of all union rules for war industries during the progress of the war. The existence of another sub-committee on the relations between capital and labor has not been announced, but you can take it that it will be very shortly. The minister of labor, John Hedges, is pledged to the idea of a commercial war, particularly against the enemy after the war. In an article prepared before he was appointed, when he was simply sitting in the House of Commons as a labor member, he wrote:

"The problem of how best to combat Germany industrially after the war is one of supreme importance, and it would be well that trade union leaders should give the matter the most intense and careful attention. The

policy of 'wait and see what is going to turn up,' savors of madness. Old customs and prejudices must be dropped by both sides if victory in the industrial field is to be attained."

And for the first time in the history of England there was a meeting between representatives of capital and labor, at the insistence of both, yet without the invitation or interference of politicians or government. This took place less than three weeks ago, between employers and trade union men of virtually all the important industries in Great Britain.

A committee of the leaders of the iron, steel, shipbuilding and engineering industries and allied trades, with a nucleus of three hundred firms, has been appointed to consider after-the-war conditions. The first report of this committee declares that increased production is the key to prosperity after the war, and this can be achieved only if the workers are guaranteed against any loss through greater output.

The British government, looking after the commercial problems of peace time, has established a department of scientific and industrial research under the joint control of the Lord President of the Council, Lord Curzon, and of the Board of Trade. A large sum of money has been placed at the disposal of this department, "to be used as a fund for the conduct of research for the benefit of the national industries on a co-operative basis." Members of the Institution of Mechanical Engineers already have donated a large sum to this department. It is to be a scientific, consulting and research bureau, always available for all work in industry, and in carrying out experiments. The universities, too, are aiding in its promotion and are doing research work for industry on their own behalf. The government has fostered the development of certain industries, chiefly for war purposes, but also, as in the case of dyes, for general needs. And a new department of coal tar industry and dye stuff research has been opened at Manchester.

When the war started one German company in England made over half of the total dyes used in Great Britain. That was eventually closed by the British government. Then there were sporadic attempts to form dye companies in England, and they all failed, until a national company was formed, and the government agreed to take on a liability of five dollars for every share sold up to five million dollars, and five dollars for every four shares sold beyond this, to a total liability of $7,500,000. Well, they fussed and fooled around with that proposition, and the stock did not sell, for the reason that the project was impossible, because the government would not guarantee protection for the industry after the war. Protection finally was promised, and the British Dyes, Limited, was established. And by the end of the first year the government had been called on to meet the greater part of its liability. At the same time the government appropriated a half million dollars for research work in the new company, and made a loan of one million dollars to the largest dye works already established, Reed, Holaday & Sons, on condition that the new company, the British Dye Company, Limited, take it over. This was done. Today the British government has invested ten million dollars in the dye industry. England's annual bill for dyes was about ten million dollars before the war. Dyes will be protected after the war. They already have produced a certain blue—I have forgotten the name of it—which it was claimed it would take ten years to develop. And they produced it in a year and a half. And when I left England one of the men in charge of the company told me that within the next six months they expected to announce three more colors, which it was feared would take them several years to produce. The company made a profit of $325,000 in the last year. The new works have twenty-seven acres of floor space, twenty-five million cubic feet of factory, and eleven miles of single railroad track. And the British output of dyes has been doubled.

The government has also taken up the question of technical education and business graduate schools, industrial schools, schools for research, in direct connection with industries that are to be established. And these will be supported by the government in the interest of trade and commerce.

A sub-committee of the Board of Trade has made a survey of twelve

industries, including paper, printing, jewelry, cutlery, leather, glass, china, earthenware, and electrical apparatus, with respect to measures for securing the position after the war of those branches. The committee recommends that the government shall institute industrial research and training on a large scale in those industries, to start with. It also recommends that all goods made out of the empire, except those made in enemy countries, which are to be labeled with the name of the country in which they originate, should be labeled "Foreign Made." Thus, there will be "British Made," "Foreign Made" and "German Made" goods. Those will be the labels that the goods will have to bear.

Then the government is going to insist—and they will not have to insist very hard, because the men of money in England agree that this is necessary —on increased assistance to industry by joint stock banks. And they are going to get away from the old cautionary methods of extending credit. They are going to be more liberal in that direction.

A Ministry of Commerce is to be established. It will be established very shortly. And the British Consular Service is to be reformed. It is to be all British, and it is going to be used naturally as an adjunct to pushing British trade.

The protection of infant industries is a recommendation of the Board of Trade, and it is the opening wedge—it is the first shoving aside of England's policy of free trade—protection of infant industries when they are of vital importance to the national safety, or are essential to other industries, that is "key" industries, as the dye industry is a "key" industry for the cotton trade of Manchester. Also they urge general protection for increased revenue to reduce direct taxation. Capital is combining to increase production and to meet foreign competition. The general tendency is toward the German Cartel.

That has already been foreshadowed in the steel and iron industries. General organizations of industries are demanding protection. One group representing seven hundred manufactures, with a million employes, demands protection for all manufactures and preferential tariffs for the British Empire and Colonies. The associations of South Wales steel employers and men are becoming strongly protectionist where they were free traders before the war.

Gentlemen, twenty-five per cent of the labor members of Parliament today are members of the most radical protection—they call it tariff reform—conference there is in the United Kingdom. And any one who, four years ago, would have predicted that would have been regarded as an insane person. But twenty-five per cent of the labor members, who belong to this tariff reform association, include all the prominent, or nearly all the prominent labor members of the House of Commons.

The Federation of British industries, comprising a vast number of manufactures, and over forty per cent of the manufacturers in the textile, dye work, iron, steel, ship-building, brewing, engineering, chemical and electrical industries, has mapped out a program of action which includes everything from financial aid for foreign commerce to the question of traveling salesmen. They are going to apply efficiency methods and salesmanship to the man who is going to have the job of selling British products after the war is over. And this federation lays particular emphasis on the development of new sources of supply for raw materials, and on the reform in the consular service, of which I spoke, so as to make it more definitely an outpost of British trade.

One week after the war broke out the commercial intelligence department of the Board of Trade—just one week—issued a list of all German goods bought in Great Britain, and arranged exhibits of samples. And at the same time it published detailed figures of every item of German trade with neutral countries, and placed the department at the service of any exporter or manufacturer. The industries in which British manufacturers have invested capital since the war begun, with a view of first supplying domestic markets, and later to compete in the world's markets, make a long list.

Among them is palm oil. They put a protective duty of ten dollars a

ton on the palm oil kernels that come out of Africa. That was the first protective duty imposed by England. And that was put on about nine months ago—ten dollars a ton.

Farm machinery has not been overlooked. The Board of Agriculture has taken that up and its purpose is to make it possible for the British manufacturer to meet the demand for more machinery of the American type when more land is put under cultivation, which is going to happen—is happening now; and particularly with a view of supplying the anticipated heavy demands from Russia.

Three concerns are now engaged in making ammonia from the air to supply nitric acid.

And when the goods are made, the shipping problem is not going to be overlooked. They are going to have not only mail subsidies but commercial ship subsidies. They have standardized the building of ships. They have standardized ship-building labor. Today, no man is idle in any ship-building plant in England or in Scotland or in Ireland. If a particular class of employes is idle in one plant because the construction of the ship has not reached the point where their services can be utilized, they are sent to another plant where their services can be utilized. And in addition to that they are building standardized ships, so that five, ten or twenty vessels can be built from the same set of plans, and the same crew of men can go from yard to yard to build those ships, just as automobiles are assembled in America. They are awake, gentlemen, they are awake.

All the chambers of commerce in England have adopted trade resolutions urging the following restrictions on peace time shipping:

Privileges to allied and neutral shipping in British ports to be only equal to British privileges in neutral and allied ports. Enemy shipping to pay double duty in British ports. Preferential tonnage and port duties for all British ships in home ports. British and allied ships to have preference in transfer of goods between the ports of the British Empire.

When the war started England was using five thousand magnetos a week, which came from Stuttgart. That firm had a factory in England. That was seized by the government and put out of business. Then the British manufacturer was asked to turn out the magneto that was necessary, and after Sheffield had produced the magnet steel they began the manufacture of magnetos. And when they passed the accuracy test demanded by the war and the navy departments, the manufacturers said, "All right, we can do this, but we must have a 33 1-3 per cent advalorem duty, not only during war time, but for a period after the war is over, and a contract and an agreement with the British government that as long as these instruments meet your requirements you will buy only British-made magnetos." They got the duty of 33⅓ per cent, and they got that contract with the government.

Now, gentlemen, that is the sort of thing that is going to happen. That is the sort of thing that this nation is going to be up against when the war is over. It is going to be up against a new, a revivified, an alert, and an efficient nation of workingmen, manufacturers, financial men and salesmen, with labor and capital combined, with the government back of each manufacturer, with the city of origin in many cases back of the manufacturer, with preferential shipping rates, with wholesale buying by the government of essential materials, as in the case of zinc from Australia, with a more thoroughly national control of all industries than the world has ever seen. And that is the kind of nation with which we have got to compete when the war is over.

There is no secret about the plan of campaign that England has laid out, and that it is working on today. They are placing their cards on the table. We can see them. Now, the question for us is, "what are we going to do to meet those conditions?" Are we going to adopt the policy of "wait and see?" That they know in England is suicide. They know its madness. They are awake. They waited in other directions, and when the moment came they were not ready. That lesson the war has taught them, the lesson of industry. I hope we do not have to have a war to teach us the lesson of industry. We

should get ready for this. The tariff commission should be appointed. It should get to work at once. We should be passing the Webb bill. We should give our manufacturers the chance to compete on even terms in foreign lands. We should get ready for the inevitable, because the clash is inevitable, and unless we are ready we might just as well quit. And what is going on in England is going on in France, in a lesser degree, and in Germany also. We are going to meet a trained army when the war is over. And today, gentlemen, we are not equipped to meet that army. Despite the skill of you gentlemen, despite the ability of the American business man, despite the ingenuity of the American inventor, despite the productivness of the American workingman, we are not equipped to meet the condition we will meet.

Now, gentlemen, in your hands, in the hands of all of us, reposes this responsibility of getting ready. It is as much your duty as it is my duty, and it is the duty of every man in Chicago and in the United States to talk about this thing and insist that something be done to get after the people in Washington, to arouse in this country some idea of the peril that we face.

Toastmaster Abbott: I will ask the friends please not to hurry away. We have a very interesting event coming yet, one full of thrills, and it will be well worth your time.

The meeting will please be at ease for a few moments while preparations are being made.

Whereupon a mock trial was staged, as follows:

One Act Tragedy.

WHY IS A STRUCTURE?

Written and Staged by Benjamin Wilk for the
WESTERN SOCIETY OF ENGINEERS'
ANNUAL DINNER

January 10. 1917.

CAST OF CHARACTERS.

Judge	Edmund T. Perkins
Clerk of Court	C. H. Norwood
Bailiff	G. C. D. Lenth
Prosecuting Attorney	R. F. Schuchardt
Asst. Prosecuting Attorney	C. A. Keller
Defendant's Attorneys	Benjamin Wilk and Albert Reichmann
James Tobasco Handley, Secretary of Board of Examiners	F. J. Postel
Dean Turneaure (expert witness)	R. H. Rice
Bion J. Arnold (expert witness)	W. W. DeBerard
John W. Alvord (expert witness)	Langdon Pearse
Isham Randolph (expert witness)	I. F. Stern
W. L. Abbott (expert witness)	Garrett T. Seely
Defendant	Arthur J. Hennebik

(Uproarious applause. The meeting thereupon adjourned.)

BOOK REVIEWS

THE BOOKS REVIEWED ARE TO BE FOUND IN THE LIBRARY OF THE SOCIETY.

THE DESIGN OF RAILWAY LOCATION. By Clement C. Williams, Prof. of Railway Engineering, University of Kansas. John Wiley & Sons, New York, 1917. 510 pages. 6 in. by 9 in

This book is intended as a text-book for technical schools, but the author expresses a hope that it will be found useful to engineers in practical railroad work. It undertakes to develop underlying principles, because, as the author states, other books have been written describing in detail the practical procedure in railway location. As the author states, many of the railways of the country are being revised and relocated, and extensive regrouping and rearrangement of systems have been made and are about to be made. He undertakes to apply in this book the more complete data now available for a more exact and scientific study of the subject than had been practicable before. The book is well written and should be generally useful, not only as a text book but for general study and reference.

The contents are as follows:

Chapter	I.	Historical Review of Railway Development.
Chapter	II.	Railway Organization.
Chapter	III.	Governmental Control of Railways.
Chapter	IV.	Valuation of Railways.
Chapter	V.	Volume of Traffic.
Chapter	VI.	Operating Expenses.
Chapter	VII.	Railway Rates and Revenues.
Chapter	VIII.	Performance of Steam Locomotives.
Chapter	IX.	Electric Traction.
Chapter	X.	Rolling Stock as Affecting Roadway.
Chapter	XI.	Train Resistance.
Chapter	XII.	Train Operation.
Chapter	XIII.	Ruling Gradient.
Chapter	XIV.	Momentum and Minor Grades.
Chapter	XV.	Use of Assistant Engines and Adjustment of Grades for Unbalanced Traffic.
Chapter	XVI.	Distance.
Chapter	XVII.	Mechanical and Economical Effects of Curvature.
Chapter	XVIII.	Line Changes and Grade Reduction.
Chapter	XIX.	Elimination of Grade Crossings.
Chapter	XX.	Additional Main Tracks.
Chapter	XXI.	Location of Electric Interurban Railways.
Chapter	XXII.	Reconnaissance.
Chapter	XXIII.	The Preliminary Survey.
Chapter	XXIV.	The Location Survey.
Chapter	XXV.	Construction Surveys.
Chapter	XXVI.	Railroad Construction Estimates.
Appendix	A.	Specifications for the Formation of the Roadway.

UNDERGROUND TRANSMISSION AND DISTRIBUTION. By E. B. Meyer, Chairman, N. E. L. A. Committee on Underground Construction and Electrolysis, 1915 and 1916. McGraw-Hill Book Co., New York, 1916. 310 pages. 6 in. by 9 in. Price $3.00.

As the author states in the preface, the policy on the part of the municipal authorities of compelling utility companies to operate their systems under-

ground, has led to the development of a specialized branch of electrical engineering, which involves large expenditures and gives rise to many operating difficulties. The author states that the book was written because of repeated requests from engineers engaged in this kind of work, and because there appeared to be no work which fully covered the general field of underground construction, transmission and distribution. A portion of the material contained in this volume originally appeared in the various reports of the National Electric Light Association Committee on Underground Construction, on which committee the author served for five years.

The contents of the book are as follows:

Journal of the
Western Society of Engineers

VOL. XXII FEBRUARY, 1917 No. 2

TIMBER DECAY AND ITS GROWING IMPORTANCE TO THE ENGINEER AND ARCHITECT

By C. J. HUMPHREY*

Presented November 13, 1916

INTRODUCTION

It is with genuine pleasure that I have accepted the invitation of your Secretary to address you this evening on the subject of timber decays. To the structural engineer and architect this subject is becoming of ever-increasing importance, due largely to the fact that the timbers which have entered into the construction of many important buildings during the past decade or two have failed to give the service expected of them.

It is a matter of common knowledge that this unsatisfactory record of service is primarily the result of using timber inferior in its resistance to decay; however, there also enter into the question in certain instances, very obvious errors in design and construction. In the earlier days, when a larger percentage of high grade structural timbers was available, delinquencies in construction did not result so disastrously and, hence, attracted much less attention from members of the engineering profession.

At the present time the greater part of the structural timber in use east of the Mississippi river consists of southern pine comprising five species, the more important of which are the longleaf, shortleaf and loblolly. The longleaf pine undoubtedly contains a larger percentage of the more durable grades than either of the other two species. Unfortunately in the trade, a confusion of the species has occurred which has resulted in the flooding of the markets, the northern ones in particular, with inferior timber cut from loblolly and shortleaf. The general demand for low-priced timber on the part of the builder has thrown the true longleaf largely out of competition, there having been, until recently, a heavy export trade in this species.

To further aggravate the situation, structural sizes of both loblolly and shortleaf have, in many cases, been cut from small rapid growth trees or knotty tops with a high percentage of sapwood, the clearer, more valuable logs being cut into 1 or 2 inch lumber.

*Pathologist, Forest Products Laboratory, U. S. Department of Agriculture, Madison, Wis.

We are now reaping the harvest from the use of this low grade stock and it is largely from this that the illustrations which I am using tonight are drawn. It is only within the past two years that better timber has become available to those who desire it and are willing to pay the price for select stock. This improvement is largely the result of the adoption by different societies and lumbermen's associations of the Forest Service density rule, which gives adequate specifications for quality grades of southern pine.

WHAT CAUSES DECAY?

Before entering the discussion further it may be well to outline to you briefly the causes of decay and the environmental factors

Fig. 1. Mycelium growing over the surface of girders and joists in a closed moist basement beneath a warehouse floor.

which promote it. Decay is due almost entirely to the growth of wood-destroying fungi within the tissues of the wood. The old "phlogiston" hypothesis of decay as taught in the older chemistry text-books which some of you may recall, has long since been exploded.

There are many hundreds of different fungi which disintegrate wood in the forest, but the greater part of the economic losses in structural timber is referable to a comparatively few species.

These fungi are plants just as much as are trees and herbs.

They differ merely in their form, lack of green coloring matter and methods of nutrition. While green plants absorb their food supplies from the soil through their roots, fungi derive their nutriment from the substance of the wood.

In the life-cycle of a wood-destroying fungus there are two distinct stages: (1) The vegetative stage, consisting of thread-like, usually much branched, filaments, termed *mycelium* (Fig. 1); (2) the fruiting stage (Fig. 2), which is nothing more than a compact mass of mycelium which takes on a definite form on the surface of the decaying timbers and serves for the production of spores and, hence, the propagation of the species.

MYCELIUM

Usually this is confined within the wood substance, the fine cotton-like filaments ramifying throughout the tissues and filling the

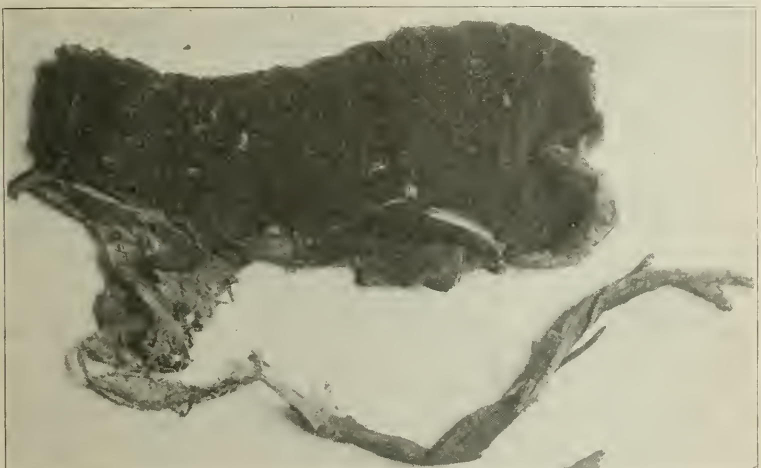


Fig. 2. Fruiting stage of the "dry rot" fungus, *Merulius lachrymans.* The pitted surface bears innumerable brown spores which can readily infect sound timber. Note the heavy root-like strand at the side. This is porous and can conduct to drier parts of the building sufficient moisture to induce decay.

pores of the wood and the cells of the pith rays, as well as boring through the walls of the wood elements. It can roughly be compared to the root system of ordinary plants for its function is the same, namely, that of an absorbing system.

In order to render the constituents of the wood available for food they must first be reduced to simpler organic compounds which can be absorbed readily through the walls of the mycelial filaments. This is accomplished by the secretion of organized ferments which have the capacity of acting chemically upon the wood and splitting up the complex compounds into their simpler components.

Sapwood is, in most cases, more susceptible to decay than heartwood because it contains a greater amount of the more easily digested compounds and, unlike the heartwood in many kinds of timber, is not infiltrated with compounds which in themselves retard the growth of the organisms.

CONDITIONS ESSENTIAL TO MYCELIAL GROWTH

In addition to available food supplies, fungi require certain essential conditions for their development. These are: 1, sufficient moisture; 2, at least a small amount of air within the wood; and 3, a suitable temperature.

Moisture. A suitable amount of moisture is, without doubt, the most important factor in decay. The different wood-destroying fungi appear to have their own particular minimum necessary to fulfill growth requirements. Certain ones classified as "dry rot" organisms seem to get along on a comparatively small amount, while others thrive only in highly humid surroundings. In the case of "dry rot" fungi it appears to be more a question of the ability of the organisms to tolerate dry conditions, or to produce their own moisture from the wood than any essential need for such conditions, for observations and laboratory tests demonstrate that an increase in the moisture under such circumstances leads to more rapid decay.

The need for at least a certain minimum of water is well shown under practical conditions. The points of failure in ordinary dry buildings are the points at which a little extra water is brought to, or held within, the timbers; for example, the ends of joists or girders set in brick or concrete walls, outer window casings, wood surrounding water pipes which may sweat or occasionally burst, porch floors and ceilings and other exposed trimmings where atmospheric moisture may collect at the joints, and last and often most important, basement timbers, either in contact with or close to moist soil.

Most people are familiar with the way in which posts and telephone poles rot at or near the ground line. Below the ground line the sapwood completely decays, while above the ground line a thin shell of dry hard outer wood remains, with the decay running up beneath it (Fig. 3). This is entirely a result of moisture conditions. The same phenomenon often occurs in water tank staves where the outer face is too dry and the inner face too wet to decay, while an intermediate zone may completely disintegrate.

This, then, leads us to the discussion of another factor in decay, namely, air.

Air. A certain amount of air within the wood is absolutely necessary for decay. The organisms need it for their growth. In saturated wood, the air is, for the most part, displaced by water and fungus growth is impossible.

The very wide-spread idea that decay is due to alternate wet and dry conditions has developed through observation of the way timbers behave when exposed to the elements. Take, for instance,

a railway tie partly embedded in soil. During a dry season it may dry out to such an extent that decay is very slow, then come the rains, and if only sufficient water falls to put the tie in a good moisture condition it begins to rot rapidly again, and will continue to do so as long as the moisture and temperature are favorable. If, on the other hand, there is a long-continued rainy period, the tie may soon become saturated and decay will stop again and remain practically at a standstill until the stick dries out sufficiently to admit the *necessary* amount of air. Thus, in the alternation of wet

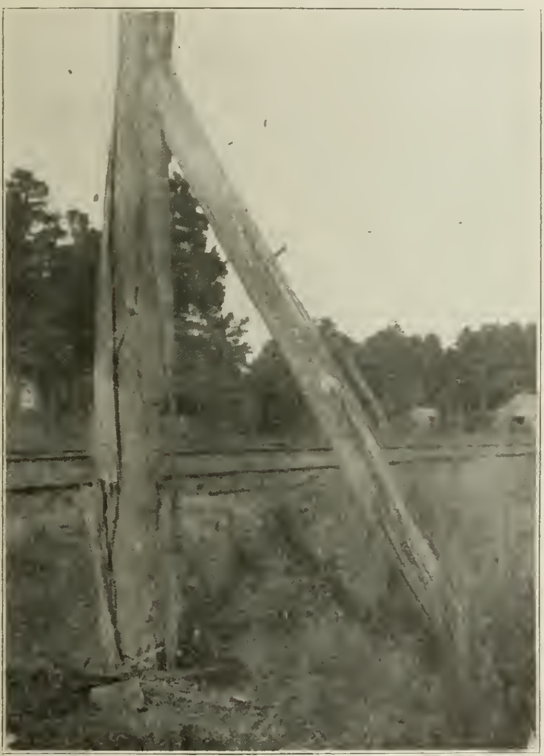


Fig. 3. Pine telegraph pole in South Carolina which has rotted entirely to the top. The outer shell has been too dry to decay and still remains hard so that it can be stripped away from the rotten core for the entire length of the pole.

and dry conditions, one gets at some point intermediate between the dry and wet ranges a condition at which decay is at its maximum. If the timber were *maintained at this optimum point,* decay of the stick would be at its greatest and the alternating wet and dry conditions *would be unfavorable.* It is only under fluctuating natural conditions that alternation becomes of advantage.

Temperature. The third essential condition for rapid fungous growth is a suitable temperature. For the majority of species the most favorable temperature lies between 75 and 85 degrees Fahr. (24-30 degrees C.). There are some exceptions to this, however, in the case of certain of our very destructive fungi. Of a series of some 50 species which we have tested in our laboratory, none would grow above 118 degrees Fahr. However, this does not necessarily mean that they would be quickly killed at this temperature.

In general, wood-destroying fungi are much less tolerant of high temperatures than low ones, the high temperature inhibition point rarely exceeding 20 degrees C. above the optimum, while temperatures slightly above the freezing point will usually permit some growth. In fact, the writer stores a large number of stock cultures of different fungi in an ice box where the temperatures vary around 10-15 degrees C. Under these conditions, several fungi isolated from building timbers grow luxuriantly.

The fact that all the species of fungi occurring naturally in a given locality can withstand the most severe winter weather shows their extreme hardiness to low temperatures. While growth may be almost completely suspended under these circumstances, the organisms will normally recover their growth capacity soon after being placed under more favorable conditions.

In the case of the true dry-rot fungus, *Merulius lachrymans,* its reaction to high temperatures is used as the basis for control measures.

Light. As a rule, light exerts a retarding effect on mycelial growth. This may amount to as much as an 18 per cent reduction.

VITALITY OF MYCELIUM

Mycelium in wood is often very long-lived in timber dried in the air at moderate temperatures. Once it gets well distributed throughout the wood, it is doubtful, in very many cases, whether the wood can again become free of infection as a result of natural atmospheric conditions. One case on record shows that a stick infected with one of our common species contained very vigorous mycelium after having been kept in a warm dry room for 4 years.

FRUITING-BODIES

The second stage in the life-cycle of a wood-destroying fungus consists in brackets or shelves, "toadstools," or often only compact incrustations which appear on the surface of the timber after decay has become well started. Their function is to produce spores, which are comparable to the seeds of ordinary green plants. Being very minute (finer than flour) these spores are readily carried about by air currents and lodging on the surface of moist timber, at a favorable temperature, germinate to produce new infections. The number of spores produced is beyond the ordinary comprehension. According to Professor Buller's studies on *Polyporus squamosus,*

the number of spores produced by a single specimen of this fungus may in the course of a year be "some fifty times the population of the globe."

A large part of the infection of timbers in the open occurs through the agency of these spores, but in buildings, where fruit-bodies are less likely to develop, they play a less important rôle.

DECAY IN BUILDING TIMBERS

Having now briefly reviewed the conditions which favor the development of rot-producing fungi, I will cite a few specific instances of the more serious fungus outbreaks which have come to my personal attention. All of these cases could readily have been prevented had the men in charge of the design and construction been familiar with the fundamental conditions which invariably lead to rapid decay.

The principal sources of danger fall, roughly, under the six following heads:

(1) Placing non-durable timber in moist, ill-ventilated basements or enclosures beneath the first floor, or laying sills in direct contact with the ground.

(2) Embedding the girders and joists in brick or concrete without boxing the ends.

(3) Placing laminated flooring in unheated buildings in a green or wet condition.

(4) Covering girders, posts or laminated flooring with plaster or similar coating before thoroughly dried.

(5) General use of non-durable grades of timber in a green or only partially seasoned condition.

(6) Use of even dry timber of low natural durability in buildings artificially humidified to a high degree, as in textile mills.

A further element of danger lies in the use of timber infected during storage (Fig. 4) or which has become infected through neglect after purchase and delivery.

Poor Ventilation in Basements. A considerable number of cases where poor ventilation beneath buildings, principally warehouses and frame structures, has started serious infections have come to the writer's notice. One case will suffice for illustration. This was a wholesale carpet and rug warehouse in a city on the Pacific coast. It was a one-story frame building four and one-half years old, with solid concrete foundations, except for four small screened ventilators in front about 5 inches by 18 inches in size. The building was set about 2 feet above the ground and the air beneath the floor was stagnant and very humid, especially at the back end, where the infection started. In the course of about three years the fungus (probably the dry-rot fungus, *Merulius lachrymans*) had rotted out a portion of the floor girders, joists and flooring, and had done some injury to stored rugs. At this time repairs were made beneath the floor and also a new floor was laid on top of the old one. In less than a year the new floor and also the bottom of racks resting on it were badly rotted, causing further injury to the carpet and rug

stock. In one case the fungus passed through the floor, the base of a rack about one inch off the floor, and twelve thicknesses of heavy rugs, eating large holes in them (Fig. 5).

Embedding Timbers in Brick or Concrete. Cases where girders and joists embedded in brick or concrete walls have rotted off in a short period of time are not uncommon. The writer has investigated one case on the Pacific coast with considerable care. This was an unheated mill-constructed building used as a hardware warehouse. Heavy 12 by 20 Douglas fir girders, in a green condition, had been covered tightly with light galvanized iron at the ends and then embedded for about 18 inches, without boxing, in concrete pillars at the outer walls (Fig. 6). In about four and one-half years many of the timbers were thoroughly rotted at the ends and had to be

Fig. 4. A highly unsanitary sawmill yard in South Carolina. Note the rotten debris scattered about. This breeds wood-destroying fungi which in turn infect the stored lumber. Hundreds of thousands of feet of lumber have rotted on this yard as a result of these conditions.

removed. In an effort to control the rot, the concrete has been chipped away from the ends of the girders to allow them to dry. Borings taken in May, 1916 (after chipping away the concrete), in two girders between the depths of 4 and 6 inches, show the following moisture percentages:

1 foot from end—19-20%
2 feet from end—14-16%
5 feet from end—11-13%

It is thus seen that the timbers were then in an air-dry condition at 5 feet from the ends. Very little, if any, rot has developed at these points.

Laboratory studies have shown that small samples of the rotten girders sent to Madison in October, 1915, and stored in a dry place until March, 1916, still retained the fungus in a vigorous condition. The optimum temperature for growth has been found to be 25 degrees C. The wood, however, will withstand a temperature of 43.5 degrees C. (110 degrees Fahr.) for 48 hours without markedly impairing the vitality of the mycelium.

Laminated Flooring. There seems to be some divergence of opinion regarding the use of laminated floorings. In many buildings it has proven completely satisfactory. In others it has given

Fig. 5. Hole rotted through four thicknesses of heavy rug after resisting for about five months on the base of a display rack over a floor severely infected with the "dry rot" fungus. *Merulius lachrymans.* This is one-fourth of a sample rug retailing at $24.00.

very poor service. All the complaints investigated by the writer have shown the trouble to be due to the use of wet material. This, at best, dries very slowly in an unheated building. Covering such timber with plaster, or any other heavy coating, when moist will almost invariably cause trouble (Fig. 7). If difficuties with laminated flooring are to be avoided, the timbers will have to be thoroughly air seasoned and kept dry during construction.

Covering Timbers. This leads us to a consideration of the advisability of covering materials in mill-constructed buildings. A number of cases already investigated indicate clearly that the prac-

tice should not be recommended except with extreme caution, and a close knowledge of the condition of the timber as it goes into the building. I will cite but one case. This occurred in a mill-constructed building in Chicago which I have been permitted to examine through the courtesy of one of your prominent engineers. This building was erected about 3 years ago, the construction being under way throughout the winter, so that the timbers were subject to periodic wetting from rains and snow. Such timbers as I have seen removed from the building on account of decay were, for the most part, of poor quality, low density, mostly rapid growth, very knotty and often with a large proportion of sapwood. Of eight

Fig. 6. Paired 12 by 20 inch Douglas fir girders. They were covered at the ends with galvanized iron and closely embedded in the concrete pier. After 4½ years' service many of them had completely rotted off at the ends. In the picture the concrete is shown chipped away and the galvanized iron removed to permit inspection and drying of the timbers.

girders and posts which were identified for species, seven proved to be loblolly pine and one shortleaf.

Laminated floors of mixed quality, usually sappy and wide-ringed southern pine, scant 3 by 6, were laid throughout the building, with the ends resting directly on the girders, with about a 6-inch bearing. The ceiling, girders and posts were all encased in plaster board (Fig. 8), leaving a narrow air space between the board and timbers.

This combination of circumstances—low quality timber, high

moisture content, and plaster board covering—caused the timber to rot rapidly, particularly at the bearings of the laminated floor on the girders.

At the time the writer inspected the building the timbers had reached an air-dry condition for a heated building and the fungus was apparently dead except on the top (seventh) floor. During the time in which the timbers were drying to this point, however, the fungus had ample opportunity to produce serious decay in many of the timbers which resulted in the removal of a considerable number.

Further details on this case, including results of strength tests on several of the decayed timbers, are soon to be published in one of the trade journals.

Fig. 7. Laminated flooring laid in a green condition and then covered with lath and plaster. Severe rot has developed during the nine years since the building was erected. The plaster was removed over this portion to permit inspection.

Use of Non-Durable Timber in Textile Mills. In textile mills where high artificial humidities are constantly maintained, the decay problem is very much aggravated.*

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*For a full discussion of this see pamphlet by F. J. Hoxie entitled, "Dry Rot in Factory Timbers," published by the Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

HOW TO CONTROL DECAY

This phase of the subject can best be discussed under two main heads: 1, Prevention; 2, Eradication.

Prevention of Infections. The possibility that timber may reach the consumer with infection already in it is by no means remote. Many lumber yards are in a highly unsanitary condition as regards the presence of destructive fungi. For this reason the material should be carefully inspected and all pieces bearing incipient rot rejected. Likewise, it may prove advisable to inspect the yard where the purchase is made.

Upon delivery of the material it should not be thrown about

Fig. 8. Type of construction in a Chicago building where serious rot developed within 3 years after erection. The posts, girders, and laminated ceiling were covered with plaster board in a wet condition. The 3-inch holes have been bored for the purpose of inspection and ventilation.

on the ground, but should carefully be placed on skids and kept dry. The soil is often a prolific source of infection.

Such timbers as are to be placed in situations favorable to decay should either be select grades of naturally durable stock or else treated with a good wood preservative. Neither non-durable timber nor sapwood is objectionable when used in a *dry* condition and ***kept***

dry. Hence, every effort should be made during construction to keep moisture away from the timbers, and especially the joints.

Moist timbers should never be cased in, nor should timber of any sort be embedded in concrete or brick walls without boxing.

In all cases thorough ventilation of moist, stagnant basements should be provided.

Eradication of Infections. Whenever timbers begin to fail, the need of a thorough inspection of the building is indicated. If poor ventilation is the cause, the building should be opened up to secure rapid drying of the timbers. At the same time tests should be made to determine whether the wood contains living fungus. It is also important to know what species the fungus is, as further control measures may hinge on its identity. For instance, the true dry-rot fungus, *Merulius lachrymans,* being a low-temperature organism, can be controlled by the application of heat, while such a procedure would be useless with most other species. Some fungi may also prove susceptible to a certain amount of drying, where others would not.

Where serious and active decay exists, without the exact method of control being indicated, the timbers should be carefully removed and replaced with select durable stock or with lower grade material treated with antiseptics. Likewise all incipient infection which appears in timbers which it is not considered necessary to remove should be given two or three applications of a wood preservative. Either a hot 3 to 4 per cent water solution of sodium fluoride or a cold 1 per cent alcoholic solution of mercuric chloride is well suited to interior timbers. Exterior timbers, where odor and color are not objectionable, can be satisfactorily treated with a good grade of hot coal tar creosote.

DISCUSSION

T. L. D. Hadwen, M. W. S. E.: I would like to ask Mr. Humphrey a question. He says here that the best thing to do is to inspect the timber for incipient rot. I would like to know how the average engineer can detect incipient rot or incipient infection. I take it he means that is not an infection that would be ordinarily noticeable in looking over the timber.

Prof. Humphrey: The detection of incipient rot requires a close inspection by a practiced eye for the best results, but the average engineer would be able to detect much of it by such characters as softer decay spots which are often lighter in color, and by the presence of obvious overgrowths of fungus mycelium on the surface of the timbers.

Mr. Hadwen: Also along the line of this question, how would you make the test for living fungi? Would you have to send in cultures and have them tested in the laboratory?

Prof. Humphrey: Yes, send them in to me and I will make the tests. I am in that business.

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P. M. Leichenko, JUN, W. S. E.: Suppose you have a building where about a million feet of lumber is used. How will you take the cultures? Suppose you have laminated flooring, posts, girders, etc. How many pieces of timber will you send to Madison to examine, and how will you select the cultures?

Prof. Humphrey: Well, I should say, perhaps, a dozen small pieces taken from various places in the building.

Mr. Leichenko: Do you think that if no fungus is found in the dozen samples, that it will be a true indication that it is safe to use the lumber? Will it be safe to consider that there is no fungus there?

Prof. Humphrey: If fungus is not detected on the first test, it is better to send more samples later. You do not need to send all of them the first time, for the first test may furnish all the data necessary.

Now, in the case of this Wabash Building, I have been receiving samples over a period of three or four months from various parts of the building. I could not get anything out of the timbers for a long time until we got up to the top floor, where I found an abundance of living fungus.

W. E. Williams, M. W. S. E.: Would it not be safer to run those timbers through a dry kiln before you put them in the building, and heat them up to a hundred and ten degrees or higher?

Prof. Humphrey: Well, that would suit us. I don't think it would be very practicable, though.

Mr. Williams: About twenty-three or twenty-four years ago in New York City they had some southern pine railway ties on the elevated railroad, which, they claimed, had been treated by high temperature, and that those ties would have much longer life than ties not so treated. They were basing the promotion of the company for the preservation of timber in that claim.

Prof. Humphrey: I do not think that would hold water very long.

J. W. Lowell, Jr., ASSOC. W. S. E.: Prof. Humphrey clearly stated that buildings should be kept dry during the construction, so that rot will not start or be accelerated. I should like to know the means employed by constructors who are doing this. The timber of buildings, we understand, should be so arranged that there will be a circulation of air around it to dry out the dampness. One of Prof. Humphrey's illustrations shows a girder supporting a laminated flooring. The top of this girder is decayed. Is not such construction a likely place to develop rot not only in the girder but also the laminated floor?

Prof. Humphrey: That was one of the very weak points in the Wabash Building.

Mr. Lowell: Since we are aware that much of the timber is infected when delivered to the contractor, how are we to tell with any degree of certainty whether the fungi are alive or dead?

Prof. Humphrey: Well, in that case we simply have the speci-

mens of rotten timber sent in to the laboratory and take minute fragments from these under aseptic conditions and transfer them to ordinary culture media on which the fungi grow very well. We then incubate the cultures for a period of three or four weeks. If alive the fungus will grow readily.

Mr. Lowell: Is there any field test by which we can expediently decide this important question?

Prof. Humphrey: No, except that after experience, you can tell, more or less, by the look of the fungus whether it is probably alive or not. It is not a safe test, however.

Mr. Lowell: Among the timber specimens on the platform, I noticed one with a blue stain in the grain. Does that stain indicate that there is or has been an infection or a starting of rot?

Prof. Humphrey: Blue stain is entirely different from rot. The mycelium does not bore through the wood cells to any extent and, of course, that is what weakens the timber. I do not know what produces the blue color in the particular sample referred to as I have not examined it carefully.

Mr. Lowell: One of Prof. Humphrey's slides illustrated how parts of timber are creosoted to protect them from rot. I should like to know if the creosote is applied with a brush or if the timber is dipped?

Prof. Humphrey: Well, that particular case was brushed, I think, with two coats of creosote. Either method is fairly good for dry timber not exposed to the weather.

Mr. Lowell: Is the timber generally brush coated before or after it is erected?

Prof. Humphrey: It should be treated before.

Mr. Lowell: Unless the timber is coated before it is erected, it would be practically impossible to coat the ends, and that is the particular part of the timber which should be coated, is it not?

Prof. Humphrey: That is the difficulty. In order to protect the joints to the best advantage, the preservative should be thoroughly applied to all contact surfaces.

F. E. Davidson, M. W. S. E.: At the present time I am a member of a committee of the National Fire Protection Association, who are drafting a code on mill construction buildings. Our report is to be presented at the annual meeting next May. The subject of the lecture this evening is one in which I am vitally interested, not only as a practicing architect and engineer, but as a member of the National Fire Protection Association.

Now, for the information of the engineers present, and incidentally of Professor Humphrey, I would like to state that in Chicago until about a year ago there was practically no good structural timber on the market. It could not be had. Until the new grading rules, which were prepared by the Forest Products Laboratory in conjunction with the American Society for Testing Materials, were adopted by the Southern Pine Association, no good structural timbers could be had in Chicago. Now, to prove that,

I am going to show you some samples. Here is a sample which is the next adjacent piece to a section that was illustrated in Professor Humphrey's lecture. This timber was sold by one of Chicago's most prominent and wealthy lumber dealers, for strictly long leaf No. 1 Southern Pine. It went into a Chicago building, and collapsed after it had been in the building about two years. The owner called on me to report on the condition of the building and repair it. I found that girder and sent the section to Madison that Professor Humphrey has shown in the pictures tonight.

The weight of that timber per cubic foot is about twenty-eight pounds. I had a letter from Professor Weiss in which he diagnosed it as probably a sample of swamp Arkansas loblolly. The building from which it was taken is a warehouse. A large number of girders were found in very bad condition. In practically every girder in that building the fibres are crushed from one-half to one inch over the bearing plates. The report made to the owner was that the economical thing to do was to reduce the loads of the building and let the building alone. We cut out the bad timber, and the building is now carrying about one-half the load originally intended.

I am sorry that the Chicago lumber dealers are not here tonight. I think they could have learned something of interest.

About one year ago, when the Illinois Society of Architects took up the question of the studying of specifications for timber, I was notified by one of the largest lumber dealers in Chicago to "lay off," or they would put me out of business. But I am still here. And the Illinois Society of Architects did adopt the Southern pine specifications, with one slight modification. For the highest grade of timber, we added the word *long leaf*. I have some interesting correspondence with the laboratories at Madison covering that particular point. We simply took the southern pine standard specifications and wrote an architect's specification as a guide to our members.

I found shortly after I was elected president of the Illinois Society, that the average architect did not know much about timber. I don't think he does today. I have seen specifications where architects specified kiln dried timber in buildings, and they all specified strictly No. 1 long leaf southern pine. As a matter of fact, for the Wabash avenue building referred to by Professor Humphrey, if I mistake not, the architect's specifications for that job specified strictly No. 1 long leaf southern pine. And you saw the samples—here they are. That timber was furnished by one of the wealthiest and the largest lumber dealers in Chicago.

The facts are these, the question of freight rates governs quite largely the class of timber carried in Chicago stock. The lumber dealers of Chicago are largely owners of southern timber lands, and naturally the lumber that comes to Chicago is the lumber which is cut from the northern districts, because it is cheaper to get it here than to ship the lumber from the South. Their good lumber

goes to Europe. You do not get a good grade of timber in Chicago unless you specify the select structural grade, or specify heart timber, and then have it inspected.

Professor Humphrey showed us some pictures of the condition of some of the lumber yards. I want to ask Professor Humphrey, representing the national government, why the government does not quarantine those yards in the same way that the Bureau of Agriculture quarantines a nursery that is infected with San José scale? Hasn't the government the same power to quarantine against a serious infection that is injurious to the property of our people? The San José scale is not injurious to life, but it is injurious to property. And the United States government actually quarantines nurseries against the San José scale, and yet the government has not quarantined these yards against the dry rot fungus, which ought to be done.

Another thing I wish to speak of. Professor Humphrey spoke of the importance of cast iron bearings and the need of plenty of ventilation around the ends of wall bearing girders, He did not mention, however, the importance of putting a cast iron bearing plate, or steel plate, under wood columns. Personally I think that is more important or just as important as to put a cast iron bearing plate under wall bearing girders.

I was employed about a year ago to design a large addition to one of the largest textile mills in Wisconsin. During construction, I was going through the basement of the old building with the owner, and noticed that the humidity was very high. I asked him if he had ever had the basement columns examined for dry rot, and he said no. I took my jack knife and jabbed into one of the columns, about eight inches from the floor. My knife blade went in about four inches. We had that building standing on jackscrews with a few hours. We cut out every basement column. They had been set directly on the concrete bases. There were no cast iron or steel base plates. In addition we discovered that all of these columns had been painted with a coat of lead and oil paint. There was a thin shell of firm wood on the outside, and the interior was absolutely rotten.

Again speaking of the Wabash avenue building, and referring to the dry rot in the laminated flooring: I have had a good many discussions with both architects and engineers about the use of laminated flooring. I don't think the average man who is writing specifications for laminated flooring knows what he is doing. I have laid laminated flooring. I have buildings with laminated floors all the way from Harrisburg in the East to San Francisco in the West, and I will defy any engineer, or the laboratory at Madison to find dry rot in any of these buildings. I will be glad to give Professor Humphrey a list of buildings from the Pacific Coast to the East.

The reason I attribute it to is this: The specifications I write for laminated flooring provide that it should be laid as it comes

from the band-saw, and not dressed. There is enough air space owing to the unevenness of the lumber as it comes from the saw to provide ventilation so that dry rot will not attack the flooring. Now, Mr. Cowing will remember a building on the north side, where an excellent opportunity was recently afforded to inspect it. It had laminated flooring of three by eights, laid last winter, and the laminations were not only water soaked, but laid when they were frozen, the building having been rushed to completion. The moment the roof was on, the floors were covered with a sheet of building paper and the maple floor placed. A slight accident which happened in the building gave an excellent opportunity to any engineer to inspect the condition of the laminated flooring. I was astonished to find that between the pieces of the laminations that I examined, there was a fungus growth, less than four months from the time the timber was placed in the building. I made the prediction that every piece of laminated flooring in that building would be ripped out in less than four years. That laminated flooring was dressed on four sides, and spiked tight, with no chance for ventilation at all.

In the building on Wabash avenue, that lumber was dressed four sides and spiked close together, with no chance for ventilation. In addition to that, the owners insisted on having all that flooring covered with plaster immediately. In my own work I will never permit an owner as long as I am in charge of the building to put any oil paint on any structural timber. If you must finish it, it should be finished with calcimine or whitewash.

One case of dry rot happened in one of the buildings designed by me, that I was not responsible for—an important building in Allegheny, Pennsylvania, where the flooring was 3 by 6 laminated. The branch manager of the company occupying the building, when he moved in, had a steel ceiling placed over the office, securing same to the underside of the flooring. About six months afterwards I received a telegram to go to Allegheny, the telegram stating that the building was falling down. I found the laminated flooring over the steel ceiling in bad condition. The steel ceiling was removed, the floor replaced and calcimined, and it is there yet.

I think that if a building is well ventilated and timber is not used in the presence of great humidity there will not be much trouble with dry rot.

John P. Cowing: I agree with Mr. Davidson in regard to laminated flooring. Laminated floor construction can be used successfully, and I am glad to hear of Mr. Davidson's success, in Chicago and elsewhere, with it. But I do know that the average laminated floor construction has been a failure, not only here but elsewhere, but particularly in Chicago, due especially to the causes assigned by Prof. Humphrey. I know now of several large buildings that are having trouble today with their laminated floors. None of them, however, are Mr. Davidson's buildings.

There is one large building here that the owner went to the

architect about—a good architect—and employed him to look after it. But he doesn't seem to know what to do with it. And I don't know what he can do with it, myself.

But the reason here for the construction of a great many laminated floor buildings, I believe, is this, that on account of the Chicago Building Ordinance, limiting the height of mill constructions to ninety feet above the sidewalk grade, the owners desire to get in as many floors as possible within that height. Laminated floor construction is used in order to secure seven floors and basement, whereas if they used ordinary straight mill type construction they could have only about six floors with the same clear ceiling height.

There is no reason why laminated floors cannot be used and used successfully, if the owner, builder, architect and superintendent will see that they get the right timber and place it in the building dry. I don't know how structural timber can be secured kiln dried, although the average Chicago architect specifies such timbers to be "kiln dried!" They don't kiln dry this kind of timber, in the first place. A majority of the timber used here comes from the south and is shipped direct to the job. Little of it comes through the Chicago lumber yards, and it must be dried out in the building.

And to that end the building should be detailed to permit complete ventilation of all wood used in laminated floors and timber construction. If the timber used is good dense timber, such building can be dried out successfully, which will eliminate the danger from the fungi mentioned by Prof. Humphrey. I do not agree with the type of construction that Prof. Humphrey indicated as being good construction, with a girder bearing on a cast iron plate only, with a box all around it. I believe wall boxes for timber girders essential and that they ought to be cast iron, or steel large enough to provide ample air space all around and over the tops of the girders.. Otherwise, it is impossible to secure proper ventilation to insure the girder against decay. No matter how carefully you write the specifications, "providing that the mason must leave an opening at the sides and at the ends of the girder and over the top," he won't do it. The best you can get is a small open joint at the side of the girder.

In laminated floors, the fungi seem to start over the girders next to the walls. The average laminated flooring material used here is cut from very small trees and is coarse grained, and especially subject to rapid decay which, once started, is infectious and spreads throughout the building.

Mr. Leichenko: I have had considerable experience with mill building construction, and have had some very interesting cases. For instance, 15 or 16 months ago we had a three story mill building where about 375,000 feet of lumber was used for laminated floors. The specifications called for long leaf yellow pine. We bought the lumber from the South. It did not look good to me, being mostly spongy, red heart lumber, with considerable sap wood,

showing a very bad cross section. But I thought before rejecting the lumber I would send some pieces to Prof. Weiss of the Madison laboratory. We sent four pieces of typical lumber, and the reply was that two pieces were loblolly culls, one was short leaf pine of very poor grade, and one was a very good grade of long leaf pine but infected.

Of course, I had to reject all this lumber and order new. Mr. Lumberman called for a number of experts—I think he had about 15 or 20—and tried to tell me that the lumber was pretty good. But, thanks to the assistance of Mr. North of the Long Leaf Yellow Pine Association at that time, Mr. Kellogg, and a few other people, we rejected that lumber and insisted upon the lumber under the new specifications. Each piece of that new lumber was stamped "Long Leaf Yellow Pine." Each piece of laminated flooring was stamped "Long Leaf Yellow Pine." The lumber was in perfect condition, absolutely dry when it got to the job. We put up the girders, placed the laminated flooring on the first floor and part of the second floor and then it rained for a week, three or four hours every day, and the building got thoroughly soaked. The only thing we could do then was to steam the building. I think we raised the temperature to about 100 degrees, and I believe we obtained pretty good results. There has been no trouble thus far, and I think there will be no trouble in the future.

I was called a few months ago to a building on the West side, built six or seven years ago. It was ordinary girder and joist construction. The building was occupied on the upper floors by a shoe factory—about four hundred people being employed on two floors. The floors sagged in some places about six inches from the center to the outer walls. On examination, the girders and joists seemed to be in fair condition. I examined the posts below the first floor and found that they sat directly on the concrete piers, and were rotted to such an extent that one could shove his hand through the posts. The thing was absolutely pulverized. I had to take it out with a shovel. Of course, we jacked it up immediately, had new columns dipped in creosote, and the building is all right now.

I have used laminated flooring in about 35 or 40 buildings in Chicago and never had any trouble. I think the buildings are in excellent condition. Some of the best mill buildings to be seen in Chicago were built under the old specifications, but some care was taken in writing the specifications and proper care was taken in inspecting the buildings to see that everything was put up right. I believe if this is followed, there will be very few failures in mill construction.

H. L. Potter: I feel that some of those present have had some excellent experiences in what is known as "passing the buck." In other words, our lumberman friend has been putting over some very poor grades on you, from your accounts of the transactions. During the past year there has been a decided movement for

betterment in the grading rules. In the past, I think the general tendency has been to trust to luck and the ability to "slip over" a certain amount of stuff. In the past, as I say, the grading rules have been, "Well, Bill, you have been grading up there with John Jones for a couple or three months, you might as well start in grading yourself. Whenever you are in doubt, just shove up the grade and trust to luck and common sense." The rule of common sense is all right were it not for the difference in common sense in different individuals. That which appears to be common sense to one man does not appear to be so to another man.

First, I would like to say I am entirely neutral. I am not advocating any one species of wood, or that manufactured by any one company or anything like that. But about two weeks ago the semi-annual meeting of the Southern Cypress Manufacturers' Association was held at Jacksonville, Florida. At that meeting they adopted the trademarking of lumber for all their association. That means that the quality of the product or the integrity of the quality is guaranteed. To make that true and to get any advantage from doing it they have also got to incorporate grade marking. Each separate grade must have a mark to bear it out and go with the trade mark. That matter was considered at the meeting, and will probably be adopted within a short time, although it has not been done as yet. And that will mean that each grade will be designated and absolutely defined, and the law of so-called common sense will be taken out of the grading of lumber.

By the application of that principle you can easily see how much easier it will be to see what you are getting and not have to fight for it. That same principle is being considered by the Southern Pine Association, and probably they will adopt the trade marking, and later the grade marking of their entire product, although nothing definite has been done upon it. They are actually considering it at the present time. If they do so, the Douglas fir interests of the Pacific Coast will naturally follow after them, because the two great structural timbers of the country are the long leaf Southern pine and the Douglas fir.

I don't suppose that you have a great deal of experience with Douglas fir in this section except with extremely long timbers. But, in time to come as Southern yellow pine is cut off, I think that you will find more and more Douglas fir coming this way.

The remark was made that they did not know how it was possible to obtain laminated floor material that was dry. I think that with the progress of the manufacture of lumber that will work itself out in a short time. The manufacturers have been shipping to sections of the country four or five hundred, yes, frequently four or five thousand miles from the mills, green lumber, fairly saturated with sap, green from the saw. That lumber can be piled and dried in the yard at about a third of the cost of the extra freight that they are paying on it. They are gradually working

themselves around to realize this, and as time goes on you will get a drier and drier product.

There is also a great field for improvement in the dry kilning of stock. I have seen a 6 in. by 6 in. Douglas fir No. 1 clear stick dry perfectly in a made-over kiln, and I think that with progress in the dry kilns it will be possible to dry any timber up to that size within 72 hours. They also have a tendency at the present time of rushing it through and injuring the material.

There are two ways in which it is possible to secure yellow pine structural timbers of the very finest quality. In the first place you can insist upon purchasing timber bearing a trade mark. Not so very many months ago, the American Lumberman started, and has nursed to strength, a campaign on the part of some manufacturers of yellow pine to trade mark their structural timbers, and to advertise the quality of these timbers. These manufacturers have excellent standing timber and are looking forward to making the profitable end of the business the sale of structural timbers. Consequently, the grade is watched very closely and by specifying a certain brand, you may rest assured that the timber you receive will agree with the specifications.

The second method may well be termed mechanical. There are certain sections in the South in which nothing but long leaf yellow pine grows. As probably all of you know, long leaf yellow pine logs cut into first-class structural timber for the reason that there is nothing else in the log. A little investigation will show you which mills have standing timber of this character, and if you will specify the brands of timber of these manufacturers, you will have two means of assuring yourself of first-class long leaf yellow pine. First, the trade mark gives you this assurance. Second, nature itself makes it impossible for you to secure any other class of timber, because it doesn't grow in that locality.

So far as I know, none of the manufacturers of Douglas fir are trade marking their product for domestic consumption, but an inspection of the class of standing timber will give you the same assurance of receiving a product of the finest quality, as in the inspection of Southern pine mills.

Mr. Davidson: Along with Mr. Potter's remarks about the branding of the timber by the cypress manufacturers, there is one manufacturer in Chicago who is today selling branded Southern pine. On one of my buildings last month, I reported three wagon loads of 6 in. by 18 in. by 18 ft. branded timber as not complying with the select structural specifications. I called up the yard that was furnishing this timber, and said: "You can have an inspection of this if you want it." But they took it away and replaced it with Douglas fir. The fact is that this particular brand of timber as handled by this particular wholesaler in Chicago is not graded, while it is all cut by the mills whose brand it bears. You will find practically any grade, and this material is being sold to the builders

of Chicago as select structural material. Now, take my advice and inspect it.

Mr. Williams: I have a friend who is close to a lumber salesman, a wholesaler. He says, "We go to a man and sell him lumber, what he thinks he wants, give him a pretty good consignment on the first shipment. The next consignment we make a little poorer, next a little poorer, and the next a little poorer, until he squeals and then we go and smooth it over and make him a concession in the way of a reduction or rebate, but after that we always send him the lowest grade that he will stand for."

The Diamond Match Company built some fine buildings at Barberton, Ohio, about 23 years ago, the largest buildings I had heard of at the time wherein laminated floors were used. They were proud of their laminated floors. I have never heard since what the results were with those floors. Does anybody here know anything about them?

In connection with the Forest Products Laboratories, here is an interesting crack in a piece of timber (showing a crack in a piece of timber). Cracks of that kind appear in tie timber and particularly on bridges. Some railroads use "S" irons with the idea of resisting these cracks. Prof. Van Schrenck showed some pictures on the screen here where "S" irons were used on the ends of ties trying to check this sort of cracking in the end of the tie. I have made some tests and observations on the different kinds of irons that would be used in tie ends to resist the spreading of the timber from those cracks. I am not satisfied with what tests and observations I have made, which are a few to what will be necessary for final determination, because the people would not pay for further work in that line.

I think it is not well known how much energy is developed in this cracking movement, and I believe that no iron such as has been used has been strong enough to resist the movement of the wood. If the laboratory gets an opportunity, I wish they would give use some data on what strains are developed when the wood starts to crack.

Prof. Humphrey: I would like to propound a few questions to you gentlemen who have been discussing a few of these points. I would like to ask Mr. Davidson first, whether he had used laminated flooring fresh from the saw, in a green condition and got good service out of it?

Mr. Davidson: Yes, sir; right from the band-saw.

Prof. Humphrey: Did you ever try casing it in?

Mr. Davidson: No, sir, never. That is one thing I would not do.

Prof. Humphrey: Mr. Davidson also brought up the question of why the United States government does not place a quarantine on lumber yards. In the first place, it should not be necessary for the United States government to take steps of that sort. I

believe the lumbermen, through pressure from the building interests, are eventually going to take care of that problem. It is manifestly to the advantage of the lumberman from an advertising standpoint, to have his lumber yard clean and free from infection. I think. also, that the timber users can organize, more or less, and patronize those lumber yards which do furnish good stock. I do not mean to say you should establish a black list or anything of that sort, but the influence should be towards patronizing those yards which furnish the clean stock.

Mr. Potter raised several points here which I would like to have further information on. He states that the principal building timbers in this middle western country are long leaf and red Douglas fir. Now, I was wondering whether he was referring to botanical long leaf or what we classify as structural timber.

Mr. Potter: I was probably referring to the kind that should be used, not the kind we have always used, especially in Chicago. I am referring to the botanical long leaf yellow pine. And by Douglas fir—red Douglas fir, I meant the young growth before it has matured.

Prof. Humphrey: Do you advocate the use of red Douglas fir in contradistinction to the yellow Douglas fir?

Mr. Potter: Yes, I do. The yellow Douglas fir is merely the old growth, ripened timber, and the knots are loose. The wood itself has not the strength that the red has, and practically all the good merchantable timber that goes for export is the red. Really there is no botanical difference between the red Douglas fir and the yellow Douglas fir. They are both Douglas fir.

Prof. Humphrey: There is quite an undercurrent of opinion with regard to the durability of red Douglas fir, and yellow Douglas fir. I happen to know one telegraph company which won't use red fir for cross arms, claiming the yellow fir is the only kind. I have personally conducted durability tests on both of those, but I don't find any difference, so I was glad to get your opinion on that.

Mr. Potter: The only explanation I can give would be that their cross arms may not be subject to great stresses, and that they might stand the weather better than the other kind.

Prof. Humphrey: I don't know that I would quite agree with Mr. Potter on his specifications for using the botanical long leaf. I do not think it is necessary. If we get the quality of the timber, that is enough.

Mr. Davidson: Has the laboratory made any investigation as to the effect of the resin content as affecting the process of dry rot?

Prof. Humphrey: For the last year and a half I have been running a series of tests on selected samples of three or four botanical species of southern pine, containing different amounts of resin. The results to date are so extremely erratic that I would hesitate to indicate exactly the influence that resin plays in the prevention of decay. I have sticks in that series of very high resin

content, 18 to 20 per cent, which rotted just as badly as some pieces which only had four or five per cent. I believe that moisture is one of the determining influences in the decay of this resinous material when placed in a highly humid atmosphere. The chances are that a highly resinous stick in a moderately humid atmosphere, will stand up better than a less resinous stick; however, a very resinous piece in a high humidity may give no better service than one lower in resin in a drier atmosphere.

I was very pleased to hear Mr. Potter's remarks on the attitude of lumbermen in being ready to supply us with a better grade, a drier grade, of timber. Unfortunately the situation has not yet advanced to that stage on the Pacific Coast. The construction engineers there tell me it is impossible for them to secure anything other than green timber fresh from the saw.

Mr. Cowing: There is a system of ventilation of the columns in mill buildings, religiously followed here by a great many engineers and architects, but I do not believe it is a good practice. My experience is it is not. This is the practice of boring a two inch auger hole down through the center of the column to ventilate it to prevent checking and decay. My experience has been in taking out some columns that I have found fungi in the bore and it seemed to be a good breeding place for such infection. Rather than being a good thing for wood columns to bore them, it seems to be the reverse. I should like to hear Prof. Humphrey's opinion on this.

Mr. Potter: I would like to suggest one thing on the specifications on the Pacific Coast. If you use the export grades—and I have known a number of companies in the interior of the country to do so—you will get a far better grade of material. There is no comparison between them.

Prof. Humphrey: Mr. Cowing asked for further views on the practice of boring columns. Before I commit myself on that, I would like others to express their opinions along that line. If there is anybody here that has had further experience, I am very anxious to get it. Is there any advantage in boring columns or is there a distinct disadvantage?

Mr. Davidson: In my practice I bore columns 12 inches and larger, principally upon the advice of men in whom I have confidence, that it would have a tendency to prevent checking. It was not with the idea of preventing dry rot, but purely with the idea of preventing excessive checking in the columns. Whether or not it is worth while I don't know. I have seen columns in buildings drying out that would check entirely through the column. In fact, there is one building in Chicago where it was necessary in less than nine months from the time the building was occupied, to bolt two sections of the column together with bolts and washers, but in a building where there was no humidity. It was a wholesale drug house where the humidity was far below normal. Some of the columns split entirely through from top to botton. We simply

bolted them together. I have seen other columns, while drying out, twist 45 degrees from top to bottom.

The timber in Chicago is not air dried. It comes directly to Chicago from the band-saw, and is water soaked, green and full of sap. As a matter of fact, as Mr. Cowing knows, in making our calculations for our timber buildings, we assume a shrinkage of at least three-quarters of an inch in every twelve inches of depth of timber, due to the fact of the timber being green.

Mr. Cowing: May I ask Mr. Davidson if the column that split had one of those post caps made of two bent "Z" plates, forming a keel let into the top of the column?

Mr. Davidson: No, sir, it has a specially built steel cap.

Mr. Cowing: I have had columns split where the column had such a post cap. Columns in seasoning tend to twist and check and such a post cap is liable to split the column throughout—otherwise a good dense timber column should not split. However, a coarse grained column or girder is liable to split through and through in seasoning.

Mr. Leichenko: Coming back to the question of the good of boring columns, I remember a column which had been bored and the cross section showed rot around the edges, and no rot at all around the place where the hole was bored through. I think it proves, for this case at least, that it does not do any harm to bore the column.

Prof. Humphrey: From the observations I have made, I should judge, from a pathological standpoint, that boring is a rather bad thing. The holes furnish a very easy passage for the progress of the fungus through the timber.

In closing. I wish to make my position clear on one further point. In giving my address this evening I have necessarily presented the worst side of the structural timber situation, for it is from this side that our object lessons are largely derived. My brief has not been against the professions and industries represented, as a whole, for among each of these certain of the more energetic and farseeing members have already introduced many improvements, and among the most important of these are the new grading rules adopted by the Southern Pine Association and many engineering and architectural societies. A close adherence to these rules in the selection of structural timber will certainly eliminate many of the difficulties which have developed in the past. Couple this with certain fundamental changes in current practice essential to the prevention of decay and your pathological cases will be markedly reduced.

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*Professor Humphrey is preparing a more detailed discussion of the Wabash Building, referred to above, which will be published later.

MODERN SEWAGE TREATMENT

By T. Chalkley Hatton.*

Presented January 15, 1917.

The three great engineering problems affecting the segregation of peoples into communities have been, for two generations past, the supplying of pure water, building of satisfactory street surfaces and the disposal of sewage.

The first has been satisfactorily solved and the purification of water is being accomplished along definite and well-established principles.

The second has passed the experimental stages so that certain classes of pavements are recognized as the best to meet certain known conditions, and aside from the usual progress which is connected with any art, no great developments can be anticipated.

The third problem has been studied just as long by equally as scientific investigators, and is far from a satisfactory solution today, because it is the most complex and abtruse one of the three.

Owing to the dense population and small water courses the cities of Europe have been confronted with the problem much longer than we have here in America and, therefore, much more has been accomplished there than here.

The three great nations of Western Europe—Germany, France and England—began the solution of this problem under similar lines, adopting, in most instances, broad land irrigation or sewage farming. After several years of such practice, however, and finding it too expensive and inapplicable to the majority of conditions, Germany and England began working along separate lines.

The first, developing fine screening and sedimentation to remove the majority of suspended matters in the sewage, as being all the treatment required; while the latter developed intermittent land filtration, sand filtration, septic and sedimentation tanks, ozone treatment and last, but most important of all, percolating filters, to the end that not only the suspended matters might be removed, but also the organic matter be oxidized and nitrified to produce an effluent subject to no further decomposition.

In both of these countries many different processes and apparatus were, from time to time, introduced, adopted and, in many instances, abandoned as unsuitable. Some of these were patented and others given to the country by their discoverer. As an example of the varied types in operation in England, the writer, in 1907, visited about 47 different sewage treatment works of which 23 were of different types in many of the most important features.

As the problem of sewage treatment came into prominence in America its engineers naturally turned to Europe for information

*Chief engineer, Milwaukee Sewage Commission.

and have adopted, with many improvements, such processes there developed as have appeared most suitable to the American conditions; so that, in this art, America has been following rather than leading.

The history of sewage treatment in America is a record of spasms, each spasm representing the general recommendation and introduction of a certain process for a time until a new one was introduced from abroad which gave greater promise.

One of the earliest spasms embraced chemical precipitation in which the solids in suspension were removed from the sewage by precipitation induced by adding lime or alum to the raw sewage. Several important plants were built of this type, the largest of which is at Providence, R. I., built about 16 years ago, and considered up to recently, a successful plant for the existing conditions.

While this process removes over 90% of the solids in suspension and a large percentage of the bacteria, it produces a turbid and highly putrescible effluent, and an enormous quantity of wet sludge of low value which must be disposed of. In many plants of this character, both in Europe and America, the disposition of the sludge has become a greater problem than the primary treatment of the sewage.

Partly by reason of the sludge problem and from the general tendency of the public to require the production of a non-putrescible effluent by sewage works, this process of treatment has practically been abandoned in this country so far as concerns the introduction of new plants.

Every one at all acquainted with sewage treatment is familiar with the spasm by which septic tanks were introduced in this country. In fact, it is so widely known that the average man, woman and child instinctively attaches septic tanks to the question of sewage disposal.

When Donald Cameron, surveyer of Exeter, England, introduced his alleged discovery some 18 years ago, it was a popular belief that the problem of sewage purification had at last been solved by a process so simple and cheap that it was within the reach of every municipality no matter how small and poor.

In fact, its simplicity and cheapness were the determinating factors in inducing hundreds of municipalities, institutions, and owners of country estates throughout the length and breadth of America to install it.

The claims made by its promoters not only appealed forcibly to the laymen, but also many well-informed engineers were so convinced of their righteousness and truth that they recommended septic tanks under all conditions.

Briefly, these claims were that the putrefactive bacteria common to sewage digested all the organic matter reducing it to harmless mineral matter which would settle to the bottom of the septic tanks, and might, at infrequent intervals, from one to several years, be removed and easily disposed of without nuisance. In other

words, this process not only solved the purification problem but also disposed of the sludge problem altogether. It takes but little stretch of imagination to realize what a boon this process promised to become to us who had long been wrestling with sewage sludge, oxidation, and nitrification problems.

This heavenly vision soon proved too good to be true, and, while septic tanks still play an important part in some sewage treatment works of considerable magnitude, they rarely form a part of the modern sewage plant; primarily because the bugs do not digest all the organic matter, and the effluent produced is very little better, and sometimes much worse than the influent, so that the solids in suspension are not completely reduced to mineral sludge and the sludge produced cannot be disposed of without nuisance.

England furnished the next spasm which has so far proven a great epoch in the history of sewage treatment. When the late Mr. James Corbitt, surveyor of Salford, built his percolating filter he made the greatest stride towards utilizing nature's agents to consume the filth produced by natural laws.

A few years after Pasteur's and Koch's discovery of the existence of the micro-organism, which induced organic decay, it was recognized by those studying methods for treating sewage that these organisms might be utilized if they were afforded proper environments, such as lodging, food and air.

To this end contact filters were introduced, embracing beds of broken stone, clinkers, or other like substances, designed as lodging for busy bugs which could be supplied with air passing through the interstices of the materials, of which the beds were composed; the food being supplied by intermittently dosing the beds with sewage from which a part of the coarser suspended matters had first been removed by screening and sedimentation.

The largest installation of this method of sewage treatment was at Manchester, England, of which Salford was a suburb, and Mr. Corbitt thus had an opportunity of observing the importance of satisfying the bugs' craving for air and food and at the same time providing against over-feeding them. Instead of flooding him with food for intermittent periods and then supplying him with a little air to assist his digestion, he decided to feed him with a little food and an abundance of air almost constantly, thus increasing his working capabilities and increasing threefold the volume of sewage which could be successfully treated upon an acre of ground.

The percolating filter embraces beds of crushed stone or clinker from 6 to 10 feet deep, a system of distributing pipes terminating in spray nozzles a few inches above the surface of the beds and spaced equidistant from 10 to 14 feet, and a system of under-drains.

Screened and settled sewage is discharged upon the surface of the beds in drops from the sprayers and percolates through the interstices between the stones or clinker to the under-drains below. The discharge is intermittent under a varying head, primarily to

distribute the sewage evenly over the bed, and secondarily, to give the bugs a little rest from their arduous labor.

This process affects oxidation and nitrification, and therefore produces a non-putrescible effluent, which, however, is usually far from clear and frequently contains more suspended matter than the influent, but of a harmless character.

Percolating filters are today the most popular and successful process of sewage treatment being operated in America. Among the larger installations might be mentioned, in the order in which they were built, Atlanta, Ga., Gloversville, N. Y., Baltimore, and Fitchburg, Mass.

It was left to Germany to supply the next spasm in the form of a sedimentation tank designed, patented and developed by Dr. Karl Imhoff, late chief engineer of the Emscher Sewage District. This tank is a two-story concern; the raw or coarse screened sewage passing slowly through the upper story, during which time from 50 to 70% of the solids in suspension settle through gas trapped slots to the bottom story.

Here the anaerobic bacteria induce rapid fermentation of the organic matters, the gases produced passing up through the liquor contained in chambers outside of, and having no connection with, the upper story. The formation and movement of these gases induce a constant disturbance of the sludge in the lower story, thus enabling all of it to be worked over by the bacteria resolving a larger percentage of the organic solids into mineral solids and producing a porous sludge from which the mixture can be separated by means of filtering through beds of stone, during favorable atmospheric conditions.

The important features of the Imhoff tank which have made it popular with American engineers, is its efficiency as a sedimentation tank, its ability to produce a minimum volume of sludge of low moisture content, possibility of sludge removal without shutting down tank, and its retention of sludge over long periods of time without creating a nuisance. This last feature makes it applicable in Northern climates because the sludge can be removed during warm weather when the drying process may be better accomplished.

In all recent installations of percolating filters, with few exceptions, the Imhoff tank has taken the place of sedimentation tanks of other types. It might, therefore, be truthfully said that the most modern and successful process of sewage treatment in America, where a non-putrescible effluent is sought, consists of coarse screening, Imhoff tanks, and percolating filters followed by final sedimentation.

Other forms of sewage treatment, which have attained more or less prominence, have been introduced from time to time, chief of which are contact filters and fine screening. The first gave many good results and many large installations are in successful operation. The last is just now being enthusiastically exploited principally by the patentees of fine screens and auxiliary apparatus, or the manufacturers and agents thereof.

It must be understood, of course, that fine screening is simply a partial treatment of sewage, designed to supplant sedimentation, and in no way comparable with oxidizing or nitrifying processes. In many situations it may satisfactorily give all the sewage treatment required, but whether it is cheaper than sedimentation is a grave question upon which many of us disagree.

In closing the above brief history of the recent development in sewage treatment, mention should be made of chlorination which has, during the last five years, assumed some importance.

Many conditions suggest as ample sewage treatment, the removal of the major part of suspended solids and the destruction of the bacteria, without attempting clarification or nitrification. To this end sedimentation or fine screening are resorted to followed by dosing the effluent with chlorine, either in the form of hypochlorite of lime, or liquid chlorine.

Without intending to discuss the efficiency of this process, the author believes that too much dependence should not be placed upon its reliability unless its operation be placed under the constant supervision of very competent men. Its efficiency depends upon time, temperatures, number and kind of bacteria, and many other controlling and fluctuating features, many of which will come and go before their presence has been established, and while a monthly or yearly record of such treatment may show a high average removal of bacteria, there are many periods of short duration when the effluent is extremely high in bacteria. This fact was well brought out in the experimental work done at Milwaukee when sterilization was tried out under many varying conditions.

There is a popular impression that electricity will accomplish about everything except the generation of human life, and a great many scientific investigators have spent time and money to adapt electricity to the purification of sewage, but so far with little practical result.

Men with but little knowledge of the vast complexity of sewage purification have developed apparatus and processes, upon which they have secured patent, for treating sewage electrically.

To assist them in introducing their goods to the public they have associated with them very able promoters who have been energetic in presenting the efficiency and economy of the process to many communities. The subject has, therefore, become too public to be altogether ignored in a paper of this kind.

The Electro Sanitation Co. of Los Angeles, Cal., has introduced the electrolytic process developed by Mr. L. G. Lautzenhiser, which consists of passing crude sewage through a trough partly filled with electrodes placed at right angles to the line of flow and connected in parallel with a low voltage electric current.

*"In brief, the theory is that the applied sewage containing

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*See Mr. Copeland's report in the Second Annual Report of the Milwaukee Sewage Commission, page 107.

table salt, and other electrolytes is rapidly decomposed by the passing electric current, forming caustic soda, nascent chlorine, hydrogen and oxygen. Part of the chlorine thus set free combines with the soda, lime and iron, thrown off from the electrodes, forming hypochlorites which attack the organic matter and destroy the bacteria."

This process has been installed in several small communities in Texas and California. The Milwaukee station experimented with it for some months, under the direct supervision of Mr. Lautzenhiser, but abandoned it as unsuitable to Milwaukee conditions.

A few years ago Mr. C. P. Landreth of the city of Philadelphia, a gentleman engaged in the manufacture and sale of belting, invented an apparatus for the purification of water by electrolysis. This machine has recently been tried out at Elmhurst Sewage Disposal plant in the Borrough of Queens, New York, the Chicago Stock Yards, and at Decatur, Ill.

It differs essentially from the Lautzenhiser apparatus in that a rapidly moving paddle is introduced between each electrode to keep its face well scoured and sewage agitated, but the theory of treatment is the same, so far as the electrolysis is concerned.

In order to affect the standard of purification sought by those interested in introducing this apparatus, large quantities of lime are added, and whether it is the lime or the electrolysis which is the most influential agent, is a matter of disagreement among engineers; but whichever way this discussion may be finally settled the cost of such treatment, so far as reliably published, has not attracted the public to any extent.

*Based on the treatment of one million gallons of sewage treated, the cost at Elmhurst was estimated to be $30.19. On the same basis, the cost at Decatur was $18.85.†

In passing from a discussion of this process of sewage treatment, the author wishes it understood that in spite of the negative results so far obtained in treating sewage by electricity, he believes that this force will eventually give more positive and encouraging results, but he does not look for such until the expert electrician, sanitary chemist and engineer get together upon a serious study of the problem.

The effect which atmospheric oxygen has upon the purification of sewage has long been studied and fairly well determined. Sand filtration, intermittent land filtration, contact and percolating filters offer different means of utilizing this effect. Numerous experiments have been conducted both in Europe and America to utilize atmospheric oxygen in intensified or concentrated form not only to clarify sewage, but also to hurry its purification.

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*Report of Engineer Commission to Maurice E. Connolly, President of the Borrough of Queens, Aug. 26, 1915, page 40.

†Report of Mr. C. F. Reynolds to Mayor of Decatur on results obtained in operating trial plant installed by Electrolytic Sanitation Company, Sept. 21, 1916, page 18.

The work done by the several species of nitrifying organisms in the decomposition of organic matter in the sewage and sewage sludge, has also been well recognized within the past few years; but it is of recent date when the discovery was made that the intimate combination of oxygen, sludge and nitrifying bacteria was essential in producing the best work from each of these purifying agents.

ACTIVATED SLUDGE.

Up to the time the activated sludge process was discovered, the aim has been in most sewage treatment processes to separate the sludge from the sewage liquor as quickly as possible, and give the bacteria of decomposition in the sludge more or less opportunity for resolving the organic matter contained therein to mineral compounds.

For instance, the proper design of the Imhoff tank provides for the rapid separation of a majority of the suspended solids from the sewage and the removal from further contact therewith. This operation removes a large portion of the purifying agents from the liquor and centralizes their effective work upon reducing the sludge. In fact, this particular feature is most prominent in fixing the popularity of this process with engineers.

The treatment of the liquor to a reasonable standard can be effected in many ways, but the disposal of the sludge is, after all, the real problem of the modern sewage disposal plant of any considerable size. The process going on in the Imhoff tank greatly reduces the volume of sludge to be handled, increases its stability, and puts it in a condition that it can be easily dewatered by simple draining.

On the other hand, the activated sludge process builds up large volumes of sludge from the raw sewage which contains from 12 to 20 millions of bacteria per c.c., among which are aerobic and facultative aerobic bacteria in large numbers, the presence of which is partly due to natural and rapid growth within the sludge. Among these bacteria are species which possess great powers of decomposing organic matter if they be given the proper environments.

It appears that air, lodging, and plenty of food are the essentials for these destroying organisms. The atmospheric oxygen introduced in the sewage supplies the air not only for the life of the bacteria, but also to keep them in intimate contact with all parts of the sewage so that they can get all the food possible. The flocculent characteristic of the sludge affords an ideal lodgement. The process really utilizes to their greatest efficiency, nature's agents for decomposing filth.

Because the activated sludge process of sewage treatment represents the most recent spasm introduced in America by those interested in such matters, the writer proposes to describe it in more detail than those that have heretofore been mentioned.

It has been about two years since the term "activated sludge" was coined, but since that time it has become quite familiar to

sanitary engineers throughout the country, and few weeks go by that some article upon the subject does not appear in the leading engineering magazines.

Many municipalities, state boards of health and industrial establishments, both in the United States and Canada, are conducting experiments, and other investigations, to determine the adaptability of this process to their several conditions, and much is being learned daily about it. Plants are being constructed at Champaign, Ill., Escanaba, Mich., Houston, Tex., and Alberta, Canada. They have been recommended at Lima, Ohio, Mattawan, N. J., and Milwaukee, Wis.

Experimental plants of considerable magnitude are being operated at Brooklyn, Baltimore, University of Illinois, Cleveland, Chicago, Milwaukee and Toronto, Canada; and, from the information so far collected, the process gives great promise of leading all other processes where the requirements demand the uniform production of a clear and stable sewage effluent and a sludge which can be converted into a low grade fertilizer.

Briefly, the process consists of forcing air, at low pressure, through a body of raw sewage of such volume and at such velocity that every part of the sewage will be agitated somewhat violently. A certain percentage of activated sludge is kept in contact with the sewage during the period of aeration, which period may be varied to meet requirements. After aeration, the mixture of sludge and aerated sewage is run into a sedimentation tank in which the sludge quickly settles, leaving the clarified liquor to pass off to its ultimate point of disposal. The settled sludge is removed constantly from the sedimentation tank, a portion of it being returned to the aerating tank, and the balance to the place of its final disposal.

There are several problems connected with the process which must be solved, and which have engaged the earnest attention of those who are carrying out the several experimental stations. The most prominent of which are minimum aeration, and sedimentation, and the economic disposal of the sludge.

AERATION.

A study of minimum aeration embraces volume of air used and period of application, both of which are intimately correlated. Other things being equal, the shorter period of aeration required the least area and plant required. The greater the volume of air the greater the operating expenses, and as the production of air is the chief item of operating cost, this problem must first be satisfactorily solved.

Its solution resolves itself into determining the proper volume to afford maximum saturation and just enough disturbance in the aerating tank to keep all of its contents in intimate contact continuously while the sewage is passing through. Of course, the great bulk of the air used is for proper disturbance, very little is absorbed by the liquor, but that little is quite essential; therefore, the air

must be delivered to the sewage in the proper form to induce the greatest percentage of absorption.

So far, the indications clearly point to the fact that the smaller the bubble of air delivered to the liquor, the greater its absorption. To break the air up into fine bubbles requires its passage through small openings in a porous material in which the frictional resistance is at a minimum.

On the other hand, there must be a sufficient velocity of air to keep the sludge in the tank circulating throughout the entire body of liquor, otherwise the heavier particles will settle to the bottom, thus removing from a large body of the liquor the purifying influences of the nitrifying bacteria attached to this sludge.

Several kinds of material have been tried for diffusing the air through the liquor, prominent of which may be mentioned the filtros plate as manufactured by the General Filtration Co. of Rochester, N. Y. It consists of fine sand pressed into plates one foot square and 1½ inches thick and baked in an oven. These plates are manufactured of any specified density and appear well suited to the requirements.

Diffusers made of bass-wood have been tried out with much promise. The wood is cut cross-grain into small blocks 2″ to 4″ square and ½″ thick and set in containers of any size required. Their advantage appears to be the breaking up of the air in fine bubbles, low frictional resistance, ease of placement and removal, and low cost. Their disadvantage is their probability of short life and possible disturbance by non-uniform swelling or shrinkage when tank is empty for any purpose.

Perforated pipe diffusers have been tried out to some extent, but so far the evidence points to an uneven distribution of air in too large bubbles, and therefore uneconomical. Their advantage is that they can be easily removed and replaced in a tank without much trouble, or without throwing the tank out of commission.

From results of experiments conducted at Milwaukee upon small tanks it appears that disturbing or agitating the sewage in the aerating tanks by mechanical appliances, while passing through a volume of air just in excess of the volume required for saturation, will have about the same effect in clarifying the sewage as agitating by means of air. We have not been encouraged in this method of treatment, however, because of the cost, operating charges, and difficulties attached to such mechanical appliances.

In estimating the volume of air required for any plant, the character of sewage to be treated and quality of effluent required must first be determined. For instance, Mr. Eddy found in treating wastes from a sheep-skin tannery, after passing through a precipitation tank in which the larger solids were retained, from 10 to 12 cubic feet of air per gallon were required to produce clarification.

Mr. Pratt found that the coarse screened sewage of Cleveland, containing 250 parts of suspended matter per million gallons, could be clarified with from 0.7 to 0.9 cubic foot of air per gallon in a

14.5 feet effective depth of tank, and that about 90% of such clarification was effected in one hour's aeration when 25% of well activated and aerated sludge was kept in contact with the sewage.

The Milwaukee experiments indicate that it will require from 1.5 to 2 cubic feet of air per gallon in a 10 foot effective depth of tank to produce clarification and stability from a sewage containing 325 parts of suspended matter per million gallons, and that clarification is effected in one hour's aeration with approximately 0.5 cubic feet of air per gallon.

In a large number of cases such clarification as is obtained by this process is all the treatment required, removing, as it does, from 95 to 98% of the suspended solids, leaving the fixed solids to be handled by dilution.

It must not be assumed, however, that one hour's aeration is all required to secure clarification. Such a short period will not keep the sludge in that condition of activity required. If the sludge is aerated separate from the raw sewage for from 2 to 3 hours and mixed with the sewage in prime condition, it should prove a more economical use of air when clarification only is desired, because the larger volume of air is then used upon the smallest volume of material being treated.

This same theory may not prove true where stability is to be secured as nitrification takes time, and during process of nitrification, air must be supplied to feed the nitrifying organisms. The city of Houston, Mr. E. E. Sands, city engineer, proposes, in the plant now being built, to aerate the raw sewage about one hour and the sludge returned to the sewage about 2 hours longer. If this proves successful it will materially reduce the volume of air now believed necessary for securing a stable effluent.

SEDIMENTATION.

The laws governing the precipitation of activated sludge differ somewhat from those of other sewage sludges. The low specific gravity of the sludge, and its tendency to flow rapidly, have two opposite effects. Its tendency to flow results in quick sedimentation (about one inch per minute), but the flow is composed of so many very light particles that the slightest disturbance caused by cross-currents loosens these lighter particles and causes them to rise and mix with the clarified liquor.

From the Milwaukee experiments it appears to be highly important to maintain through the sedimentation tanks, a uniform velocity of flow in one direction of not more than three feet per minute, and to remove the sludge continuously from the bottom of the tank. If the sludge is permitted to accumulate to any considerable extent, there is a greater tendency to pick up the finer floc and sweep it out with the effluent.

The tendency of the sludge to rapidly form in floc and settle quickly has fooled most of the experimenters in designing their sedimentation tanks. The first indications pointed to a maximum

sedimentation period of well activated sludge of 15 to 20 minutes, but recent developments have proven that 40 to 60 minutes are nearer the requirements, although it depends not so much upon the detention period as upon the uniform flow in one direction throughout the body of the tank.

The early sedimentation tanks built had sloping bottoms of about 45°. These were found too flat, the sludge alighting thereupon would not slide down to the sludge outlet and would become septic in a very few hours. The bottoms of the recent tanks have been made with a slope of from 60° to 75°, the latter appearing to be the most efficient.

The writer would call the young engineer's attention to one point which might well escape his notice but which is quite important in the successful operation of a sedimentation tank, and that is the size of the draw-off sludge pipe. Assuming that the settled sludge is to be removed by an air lift (and so far this method appears the most logical), the pipe should be of such diameter that a minimum velocity of from 2 to 3 feet per second will be maintained through the pipe. This insures the removal of the densest sludge instead of the removal of the liquor mixed with a small volume of the sludge.

SLUDGE DISPOSAL.

After all, the sludge disposal is the most complex and important problem connected with this process, as it is with all other processes of sewage treatment. Large quantities of wet sludge are produced from the activated sludge process, produced constantly, and must, therefore, be disposed of constantly. It cannot remain standing quiescent in a reservation tank without becoming septic within 48 hours.

The volume of sludge produced depends largely upon the amount of suspended matter in the sewage and the aeration given. The experiments carried out in Milwaukee indicate a production of one-half a ton of dry sludge per million gallons of sewage containing 325 parts of suspended matter per million after passing one-half inch bar screens, and where no attempt has been made to reaerate the sludge.

To produce this one-half ton of dry sludge requires the handling of about 14,000 gallons of sludge containing about 99% moisture. The proper handling of this large volume of wet sludge becomes largely a local problem and depends upon several conditions.

If the sewage is a representative city sewage and amounts to more than 5 million gallons per day, its value as a fertilizer may warrant the cost of reducing it to that form.

If such reduction is not warranted, and waste lands are available, the sludge may be partially dewatered by pressing and drying and deposited as a fill upon such waste lands.

If no waste lands are available, the sludge may be pressed or

dried, stored until the proper season for fertilizing near-by lands, and spread thereover as barn manure is now used. This last mentioned disposition is, perhaps, the only one adaptable to very small plants unless low ground is available.

From the Milwaukee experience, there seems to be no doubt that in large installations it will pay to reduce the sludge to a marketable fertilizer. Just how this can most economically be done is still undetermined. Sufficient experiments have been made and data obtained, however, to warrant the following conclusions:

A 99% moisture sludge can be reduced to 96% by settlement from 1 to 3 hours in proper shaped tanks. This sludge can be subsequently dewatered by pressing in presses of different type to 75% moisture, and can then be dried in either direct or indirect driers to 10% moisture (which is the moisture allowable in commercial practice), for from $6 to $8 per dry ton, including overhead charges.

From numerous analyses taken of the Milwaukee sludge, the available ammonia content averages 5%, or 100 pounds per ton. The market value of this ammonia runs from 10 to 17 cents per pound, making its selling value from $10 to $17 per ton. Based on producing one-half ton of dry material per million gallons of sewage treated, this shows a net profit of from $1 to $4.50 per million gallons of sewage treated, assuming the reduction of the sludge amounts to the maximum cost herein estimated.

In view of the large first cost for equipment necessary to reduce the sludge to a fertilizer, and the necessary co-operation with business interests, which may prove uncertain where a municipality is concerned, this seems a very small and unattractive profit. The fact, however, must not be lost sight of that by this method the sludge is finally disposed of without nuisance, and even though no profit results, the method is far in advance of any other known method of sludge disposal *which costs money,* no matter what method is used, and, as its volume increases, becomes the greatest problem to the municipality.

Numerous instances could be cited where the municipalities began by disposing of their sewage sludge with little expense and difficulty, but as the amount increased, this expense increased and the great difficulty arose as to what disposition could be made of it, regardless of expense. Just a few days inspecting the older sewage plants of England will convince you that disposing of sludge upon nearby low-lands, sooner or later, becomes an unmitigated nuisance, not only to the surrounding neighborhood, but also to the operator of the plant. In fact, this condition can be observed in America at any considerable sized plant. It has been suggested that the city of Chicago dispose of its sewage sludge by making up the lake front. A visit to Toronto, Canada, where the sludge from Dartmouth tanks is being used to fill up the low ground, will convince the average observer that this cannot be done.

It has been a popular idea that the value in sewage should

be conserved, but until activated sludge was produced sewage sludges contained such a low value that few municipalities felt warranted in conserving it. This process, however, puts an entirely different aspect upon the question. It is true, as Messrs. Pratt and Gascoigne, of Cleveland, suggest in their very valuable paper on Activated Sludge Results, appearing in Engineering News of December 14, 1916, page 1128, that "a revenue from activated sludge involves a large initial expenditure, co-operation with private interests and a commercial demand"; but if one feels confident of producing an article the public will want, he is sure of the demand, and the writer, at least, is not afraid to trust to private interests for fair treatment, particularly in view of the present wide competition in the purchase and sale of low-grade fertilizers. A large city, undertaking the reduction of garbage, faces the same problem; and yet, in the light of recent developments, it would hardly erect an incineration plant because of this problem. If inventors and promoters the world over had been afraid of first cost of production, and probable demand, their inventions would never have seen the light of day and the world's progress would have been a dream. The governments of our American municipalities are not so incompetent and dishonest that they cannot, with profit and success, enter into a commercial proposition when such is necessary to conserve the public health. All that is needed is confidence that you have a good thing and you will soon convince the public that it needs it.

Conclusion:

This paper started out to be a general discussion of the modern methods of treating sewage and, far from the writer's original intention, winds up with an earnest plea for the activated sludge process, but the only excuse he can offer is that for the past two years he has worked, played and slept with it; has suffered many disappointments and enjoyed more successes; that his confidence in its final success is so great that he has staked his reputation in recommending it and having it adopted as the process to be installed in the city of Milwaukee; that he realizes there are a great many phases of the problem yet to be solved, some of which time and plants in operation alone can do, and that, after 25 years of actual practice in experimental work, designing and constructing sewage disposal plants, this process gives greater promise of satisfactorily solving a complex problem than any other so far introduced. It is not going to be the panacea for all ills, but will mitigate more of them than any other process, and all it needs is the enthusiastic co-operation of a lot of first-class engineers and chemists.

The attitude of the sanitary engineer towards sewage disposal problems must change before they can be satisfactorily solved. We have been too prone to consider cost of plant and operating charges as the primary recommendation of design, the satisfactory operation and results coming in as a secondary consideration. The comparative cost per capita has played too great a part in considering

the system of disposal best adapted to existing conditions. Had water filtration been carried on under this policy it would never have attained the successful development it has today. With it, the paramount question has been successful and uniform results, let the costs be what they may.

With a few notable exceptions, the sewage disposal plants in America have utterly failed to produce a uniform effluent satisfactory to their designer, and yet millions of dollars have been expended upon this work. The fault is probably equally divided between the designer and the public. The first, because he is confronted with, and succumbs to the public's demand for the expenditure of just as small a sum as possible for this work, and the comparison of such cost which his design must bear to some other plant in the vicinity; his failure to realize that the plant he builds will not be given the trained supervision it demands unless it embraces machinery which must be given constant attention.

The second, because the public is not yet educated to the necessity for exercising the same care in disposing of its sewage as in furnishing its water supply, is only induced by rigid necessity to the expenditure of funds for installing or operating plants for such purpose, and views the subject from the standpoint of appeasing public clamor only.

The writer does not want to be understood as recommending the expenditure of needless funds for producing a sewage effluent far above the standard required by existing conditions, but he does believe in establishing the required standard and designing such a plant that the designer may feel pretty well assured that a careless public will be forced to operate it to produce such a standard; otherwise a wilful waste of public funds is inevitable.

It has not been the purpose of this paper to enter into a technical discussion of the subject of modern sewage treatment, but to present it in such form as may prove of interest to the engineer who is concerned in it, more from the view-point of a good citizen interested in all important problems which affect the public welfare.

THE PURIFICATION OF SEWAGE IN THE PRESENCE OF ACTIVATED SLUDGE, ILLINOIS

By Edward Bartow, F. W. Mohlman and J. F. Schnellbach.

Presented January 15, 1917.

During 1916 experimental work in the treatment of sewage by aeration in the presence of activated sludge has been continued at the Sewage Experiment Station of the Illinois State Water Survey at the University of Illinois. In previous articles* we described a series of experiments begun November 1, 1914, and conducted in three-gallon bottles; a second series of experiments conducted in a tank 9 inches square and 4½ feet deep and a third series of experiments conducted in 4 tanks each having an area of 10 square feet and a depth of 9 feet. These experiments were carried on by the fill-and-draw plan. For a fourth series of experiments we have operated a continuous flow plant. The septic tank designed by Professor A. N. Talbot† in 1897 for the city of Champaign was reconstructed early in 1916 with the expectation that 200,000 gallons of domestic sewage could be treated daily. The plant contains a screen chamber and pumping pit, a grit chamber, an aerating chamber, a settling chamber, a blower room, and a laboratory containing sludge-drying apparatus. A sludge-drying bed, and a pond into which the effluent from the process may be discharged, are also provided. The sewage is drawn from the main outlet sewer of the city of Champaign. The daily flow is estimated to be from one to one and one-half million gallons of sewage, though in wet weather, owing to seepage into the sewers, the amount of flow is greatly increased. The manhole nearest the septic tank was modified to serve as a screen chamber and suction pit for the pumps. A weir was placed in the outlet to raise the sewage level and provide suction for the pumps. A screen with vertical bars spaced with three-fourths inch openings prevents coarse material from reaching the pumps. The sewage is pumped to the grit chamber by two centrifugal pumps, having a capacity of 75 and 110 gallons per minute, respectively. Each pump is belt-connected to a 3-horse power electric motor. The grit chamber is 34 feet long, having two compartments each one foot wide. At the outlet is an adjustable weir through which the sewage must flow and where its rate is measured. The sewage flows from the grit chamber into the aeration chamber, a rectangular concrete tank 17 feet by 36½ feet in plan and 9½ feet deep, having a capacity, after allowances are made for baffle walls and sloping bottom, of about 36,000 gallons. The chamber is divided longitudinally by 3 baffles into 4 compartments through which the sewage flows a distance of about 140 feet. The lower part of each compartment has sides sloping toward the center to a channel 12½ inches wide and 4

*J. Ind. Eng. Chem. *7*, 318 (1915); *8*, 15-16, 17-20 (1916).
†Engineering News, *42*, 111 (1899).

inches deep and extending the length of the compartment. Above this channel filtros plates are supported on T-bars which were imbedded in the concrete. The channel below the filtros plates was divided into sections for 6 filtros plates each, with the expectation that each set of plates would be separated from all the others and that the supply of air to each set could be regulated by an air pipe and valve. Owing to the porosity of the sloping concrete sides it was impossible to regulate independently each set of plates.

The aeration tank was calculated to be able to treat 144,000 gallons of sewage and sludge daily, if aerated during a period of 6 hours; 170,000 if aerated 5 hours; 216,000 gallons if aerated 4 hours. The treated sewage and sludge flows from the aerating chamber to the settling chamber. The settling chamber is 6 feet by 10½ feet in plan and 11 feet deep at its lowest point, having a capacity of 3,700 gallons. If the flow passed through all the tank it would have a retention period of 24, 31 and 37 minutes with a flow through the aeration chamber of 4, 5, and 6 hours respectively. In order to assist the settling of the sludge the liquid is passed down into the center and up around the edge of a hollow frustrum of a pyramid in the center of the settling basin. The frustrum of the pyramid is 15 inches square at the top, 3 feet square at the bottom, and extends to within 5 feet of the bottom of the chamber. From the settling tank the effluent flows over a weir and is either returned to the sewer or discharged into the pond. The pond is formed by two dams thrown across the abandoned bed of a stream. It covers about 0.1 acre and its maximum depth is 3 feet.

The sludge is withdrawn from the settling chamber by an air lift and can be discharged into the raw sewage where it enters the aeration chamber, or can be diverted for experimental purposes, or can be discharged into the sewer. Air is supplied for aeration and for the air lift by a rotary positive-pressure blower having a rated capacity of 300 cubic feet per minute, driven by a 15 horsepower electric motor. The air is passed through cheese cloth, spread over a box having sides of wire netting, before it enters the blower suction pipe. The air is measured through a Venturi meter.

OPERATION OF THE PLANT

The plant was put in operation May 25, 1916, but since there was an escape of air along the sides of the baffle walls, the plant was operated only until June 11th, when it was shut down for repairs. The holes resulted from faulty concrete work and from the difficulty in making a tight joint between old and new cement. The holes were satisfactorily filled. This difficulty should emphasize the fact that very careful concrete work is essential if the plates are to be set above concrete. Cast iron or metal frames as used at Milwaukee* and Cleveland† may be found preferable.

*T. C. Hatton, Eng. Record, *72*, 481-4 (1916).

†R. W. Pratt and G. B. Gascoigne, Eng. News, *76*, 1061-6 (1916).

The plant was again put in operation on July 11 and except for a few shut-downs for repairs or to add additional equipment, was operated until October 22.

The sewage was measured every two hours by observations of the flow over a V-notch weir. After September 30th the combined sewage and sludge was measured at a 24-inch rectangular weir at the entrance to the settling basin, the amount of sludge returned being equal to the difference between this volume and the volume of sewage.

Air was measured every two hours by observing the pressure on a Venturi meter having water in the manometer. The air used in the air lift was not measured.

The percentage of sludge by volume in the aerating chamber and in the liquid returned by air lift from the settling chamber was determined at 4-hour intervals, in 1000-cc. cylinders.

Temperature of the raw sewage and of the effluent was observed every two hours.

Samples of the effluent were taken every 4 hours and incubated at 37 deg. C. with methylene blue.

Dissolved oxygen in the effluent was determined at irregular intervals.

Four-ounce samples of raw sewage and effluent were collected every two hours and placed in gallon bottles containing chloroform. The composite sample collected during 24 hours beginning at midnight was analyzed in the laboratory of the State Water Survey.

OPERATING RESULTS.

Modifications in the manner of operation were made at intervals in an attempt to determine the method of obtaining the highest efficiency. The time of operation is, therefore, divided into periods and average results are determined for each period (see Table 1).

First Period July 11-29. The machinery was being regulated so that the operation would be uniform. The sludge increased slowly, the amount present varying from day to day according to the conditions of operation. The amount of sewage pumped averaged 110,000 gallons per day. The amount of air used was 2.2 cubic feet per gallon. In spite of the non-uniformity in the operation and although there was no sludge at the beginning and only a small amount of sludge during the whole period, the results obtained were very gratifying. There was an average removal of 79 per cent of the suspended solids and the affluent was stable for 20 hours at 37 deg. C. No increase in nitrate nitrogen was obtained. Raw sewage was normal though it contained 0.7 part per million of nitrate nitrogen.

Second Period July 30-August 15. Amount of sewage pumped was decreased to 81,700 gallons per day. The amount of air was

AVERAGES

Operation and Control of Plant, Sewage Experiment Station, Illinois State Water Survey.

Date Inclusive	Gal. Sludge Returned	Rate of Flow Gallons Per Day	Ratio Sludge Sewage	Period Hours Aeration	Air		Per Cent Sludge Aerating Basin	Temperature Centigrade		Per Cent Sludge Air Lift	Decolorization Methylene Blue Hours	Relative Stability Effluent
					Cu. Ft. Per Day	Cu. Ft. per Gallon		Raw	Effluent			
July 11-29.....	......	110,500	..	..	232,500	2.2	12	19	20	..	20	33
July 30-Aug. 15	......	81,700	..	..	219,400	2.7	15	21	22	67	50	64
Aug. 16-Sept. 5	......	61,100	..	..	175,400	2.9	24	22	23	51	90	90
Sept. 6-12....	......	69,100	..	..	146,700	2.1	23	23	23	48	38	55
Sept. 13-18....	......	82,200	..	..	188,000	2.3	22	22	23	45	105	96
Sept. 19-22....	......	130,000	..	..	258,500	2.0	16	22	23	31	100	95
Sept. 23-28....	......	177,600	..	..	289,500	1.6	13	22	23	26	35	52
Sept. 29.......	......	92,700	..	..	291,600	3.1	18	22	23	47	42	62
Sept. 30-Oct. 13	144,000	143,200	1.09	3.0	290,800	2.0	19	21	22	38	41	59
Oct. 14-22.....	112,000	152,300	.73	3.2	298,300	2.0	23	21	22	48	60	74

Plant shut down September 29 from 10 a. m. to 7 p. m.

increased to 2.7 cubic feet per gallon. The sludge increased to only 15 per cent in the aerating basin and it is probable that the large amount of air used prevented a greater increase. Similar results were noticed when the material in the fill and draw tanks was over-aerated. Even though a small amount of sludge began to rise in the settling basin and to overflow with the effluent, and even though a slight amount of septic sludge was noticed in the settling basin, the results showed great improvement over those of the first period. Ninety-two per cent of the suspended solids were removed and the effluent was stable for 50 hours at 37 deg. C. A slight increase in the nitrate nitrogen was noticed. The raw sewage was normal, though the content of chloride was high.

Third Period August 16-September 5. Because it seemed impossible to keep sludge from going over with the effluent by increasing the amount of sludge pumped, the amount of sewage pumped was reduced, thus decreasing the velocity of the flow. The smallest quantity of sewage, 61,100 gallons per day, was treated with the largest amount of air, 2.9 cubic feet per gallon. The sludge increased to 24 per cent in the aeration chamber and the liquid pumped back contained 51 per cent after settling for one-half hour. Septic action in the settling basin was prevented by brushing the sloping bottom several times a day. Excellent results were obtained. The effluents were stable for 90 hours at 37 deg. C., 3.3 parts per million of nitrate nitrogen were present. Eighty-nine per cent of the suspended solids were removed and there was an unusually large removal of ammonia nitrogen. Raw sewage continued normal during this period. Although purification was excellent, the amount of air used was excessive and the amount of sewage treated was much below the rated capacity of the tank.

Fourth Period September 6-12. The amount of sewage pumped was increased slowly to 69,100 gallons per day. Concentration of the sludge in the aerating chamber and the concentration of the liquid returned was almost the same as in the preceding period: 23 per cent and 48 per cent, respectively. Air was decreased to 2.1 cubic feet per gallon. The effluent was satisfactory, although the average stability was lower during the first three days. During a heavy storm on the fifth day, power was turned off frequently and the operation was more or less irregular, so that considerable sludge escaped with the effluent. This caused the effluent to decolorize methylene blue very quickly. For the whole period nitrate nitrogen averaged 3.9 part per million and ammonia nitrogen was reduced 54 per cent. Suspended solids were reduced 94 per cent, there being an average of only 7 parts per million in the effluent.

Fifth Period September 13-18. The amount of sewage pumped was increased to 82,300 gallons per day and the average amount of air used was 2.3 cubic feet per gallon. The sludge remained about the same. Excellent results were obtained. The effluent was stable for 105 hours at 37 deg. C., affording the most satisfactory effluent obtained in any period of operation. Nitrate nitrogen increased to

3.4 parts per million. There was a removal of 97 per cent of the suspended solids.

Sixth Period September 19-22. The amount of sewage was increased to 130,000 gallons per day. The amount of air was decreased to 2 cubic feet per gallon. The concentration of the sludge in the aereating basin decreased from 22 to 16 per cent and in the liquid returned from 45 to 31 per cent. The quality of the effluent was not seriously affected, it having an average stability of 100 hours at 37 deg. C. There were 4.2 parts per million of nitrate nitrogen in the effluent and 94 per cent of the suspended solids were removed. The raw sewage was unusually strong during this period, containing 1,368 parts per million of total solids, 433 parts per million of suspended solids and an oxygen consuming capacity of 93 parts per million. Considering the amount of sewage treated and the quantity of air used this was the most satisfactory period during the test. Sludge escaped frequently with the effluent, but because of the insufficient settling capacity and not because of the process itself. The effluents were allowed to remain quiescent for one-half hour and the supernatant liquid taken for examination.

Seventh Period September 23-28. The amount pumped was increased to 177,600 gallons per day. The air used was 1.6 cubic feet per gallon. With such a rapid flow only 13 per cent of sludge could be retained in the aèration chamber. Owing to the small settling chamber the period of settling was so short that a large amount of sludge escaped and the liquid which remained contained only 26 per cent of sludge after settling one-half hour. The amount of sludge pumped back was probably equivalent to the amount of sewage treated, so that the retention period in the aeration chamber was reduced to approximately 2.5 hours. The effluent stability was only 35 hours at 37 deg. C. Only 1.0 part per million of nitrate nitrogen was obtained, but the clarification was good, 95 per cent of the suspended solids being removed. This period with its maximum sewage flow indicated that well clarified effluents with a considerable degree of stability could be obtained if sufficient settling capacity were available.

The plant was shut down for ten hours on September 29 while channels were being constructed around the perimeter of the settling basin. Filtros plates were built into one side of the basin with the hope that the effluent would filter through the plates, but they became clogged and the effluent ran over the top as before. By taking the effluent from the entire perimeter of the tank instead of from one side, the efficiency of the settling basin was increased.

Eighth Period September 30-October 13. The amount of sewage pumped was slightly reduced to 143,200 gallons per day. The air was increased to 2 cubic feet per gallon. The sludge increased to 19 per cent in the aerating chamber and to 38 per cent in the liquid returned. The sludge put into the aeration chamber was 1.09 times as much as the sewage, thus giving a period of aeration of only three hours. The results of treatment were better than during the

preceding period. The average stability was 41 hours at 37 deg. C. There was no appreciable formation of nitrate nitrogen, possibly because of the excessively strong sewage treated. During this period it contained 1,622 parts per million of total solids, 517 parts per million of suspended solids and the oxygen-consuming capacity was 80 parts per million. The clarification obtained was excellent, there being but 11 parts per million of suspended matter in the effluent, equivalent to a removal of 98 per cent of the suspended matter present in the raw sawage. The results of this test show the fallacy of reporting purification in percentage decrease in oxygen-consuming capacity. The greatest percentage removal is shown during this period, but owing to the large amount of organic matter in the sewage only a low degree of stability was obtained. The content of nitrate nitrogen of the effluent was low and ammonia nitrogen decreased but slightly.

Ninth Period, October 13-22. The amount of sewage pumped was increased slightly to 152,300 gallons per day. The amount of air was the same as before, 2 cubic feet per gallon. The concentration of the sludge increased to 23 per cent in the aeration chamber and to 43 per cent in the liquid returned.

The sludge pumped back was 73 per cent of the sewage pumped. The quality of the effluent improved materially, having an average stability of 60 hours at 37 deg. C. There was .7 part per million nitrate nitrogen present in the effluent. On the whole this period was very satisfactory. The amount of sewage treated was high, the sludge was well activated and the effluent satisfactory.

Operation was most successful during the periods of September 19-22 and October 14-22, in which 2 cubic feet of air per gallon of sewage were used to obtain stable effluents. This amount is higher than the amount required in the experiments in the fill and draw tanks. It is probable that some air escaped from the concrete channels without passing through the sewage, and for this reason better efficiency might be obtained with a more satisfactory installation for air distribution. The settling tank was too small and the insufficient slope of the bottom (45 deg.) caused some sludge to be retained.

The actual period of flow through the settling tank was considerably shorter than the theoretical period. To find the actual retention period 5 pounds of salt and 20 grams of fluorescein in solution were added at the top of the frustrum of pyramid in the settling chamber. The fluorescein was detected in the effluent in 10 minutes. The salt was at its maximum in the effluent in 15 minutes and the quantity began to decrease in 20 minutes. The rate of pumping on the day of the test was 133,900 gallons. The capacity of the settling basin would give a theoretical retention period of 34 minutes and the actual retention period was found to be less than 20 minutes. The error in calculating the necessary retention period was due to calculations made from our fill and draw tanks, where satisfactory settling was obtained after 30 minutes of rest. In ver-

tical flow settling tanks the velocity of flow must be less than 8 feet per hour,* in order not to carry the sludge away. The possibility of settling the sludge in a second tank before it is pumped back to the sewage might prove practicable.

From our experiments and from the data obtained through the press or by correspondence with others we are led to believe that the successful application of the activated sludge process depends to a great degree upon the practical solution of the problem of dewatering the sludge. Since drying on sand beds and centrifuging were being carefully tried at Cleveland, the Berrigan press, made by the Worthington Company, and the press of the Simplex Ejector Company were being tried at Milwaukee, it was planned to use another method. Through the courtesy of the Koering Cyaniding Process Company of Detroit a rotary press was furnished such as has been used satisfactorily in filtering slimes in extracting gold and silver by the cyaniding process. Owing to difficulty in obtaining the metal parts the company was delayed in furnishing the press. For this reason and because of shortage of funds we felt obliged to shut down our plant October 22, until the sludge dewatering apparatus could be installed.

This apparatus has now been installed and consists of a cylinder of filtros plates supported on a perforated steel cylinder outside of which at a distance of about one inch is a solid steel outer shell. The material to be filtered is forced into the interior of the cylinder of filtros plates. The cylinder will be revolved and a cake of sludge will be built up on the inside of the filtros plates. The liquid filters through the plates into the space between the inner and the outer shell and is drawn off through outlets in the outer shell. Air pressure can be exerted from the interior to dry the cake and from the exterior to loosen it. The plates can also be cleaned by back-flushing with water.

The Koering Cyaniding Process Company has also installed an apparatus for concentrating the sludge before its application to the rotary press. This concentrator consists of a cast-iron box 2 feet square and 4½ feet deep, inside measurements, lined with filtros plates. On the outside of the filtros plates are 4 independent compartments through which the filtrate may be withdrawn or into which air or water may be forced for cleaning the plates. It is expected that the liquid sludge may be considerably concentrated in this apparatus so that the capacity of the rotary press may be greatly increased.

Since its operation has been temporarily discontinued several modifications were made in the plant. Owing to the reported success by other investigators with special aeration of the sludge, the first quarter of the aeration tank has been separated from the aeration chamber by a baffle and divided into 2 parts by another baffle. The point for in-flow of the sewage has been changed so that it may

*Hatton, T. C., Eng. Rec. 75, 16 (1917).

be added one-eighth or one-fourth of the distance through the aeration chamber. This would mean that one-eighth or one-fourth of the capacity of the tank can be utilized for aerating sludge. A settling tank has been constructed into which the sludge may be passed after the special aeration and from which it can be pumped to the sludge dewatering apparatus.

From our experience we must conclude that it is entirely possible to treat satisfactorily approximately 75,000 gallons per day of Champaign sewage by the activated sludge process with the aerating and settling capacity now provided. Double the capacity can be handled in the aeration chamber if additional sedimentation were provided. We hope other designers may profit by our experience and provide ample settling tanks.

DISCUSSION.

Professor Bartow: Mr. Hatton made a statement that there have been fads at different times. These indicate the progress of the art. I am reminded of a prophecy made by Dr. Dunbar of Hamburg in 1914. He prophesied that the Imhoff Tank would be out of date in five years. He had in mind a tank which had been built under his direction in Germany and which he thought would be very successful. If the Imhoff Tank is put out of commission in large installations in five years it will be rather by the activated sludge process than by the tank which Dr. Dunbar had in mind.

I should perhaps correct Mr. Hatton. The plant at Champaign is to treat only about one-tenth of the Champaign sewage. No steps have been made toward building a larger plant in the near future.

Mr. Hatton spoke of the plant at Birmingham, England, and of the work of Dr. Watson. Within a few days a letter has been received from Dr. Watson in which he mentioned the activated sludge process in England at the present time. He has no doubt whatever of its efficiency as a process for treating sewage, but he has considerable doubt as to its economy, and criticizes the English authors who have thus far given no figures as to the cost of the process.

I want to emphasize what Mr. Hatton has said with regard to the disposal of sludge. While we may not be able to get a direct financial return from activated sludge, it would seem to me that we must consider the difference in cost of disposing of sludge obtained by other processes and the cost of disposing of sludge by this process. If we could break even, that is, the sludge as a fertilizer could pay for the cost of disposing of the sludge, we would have gained the three to five dollars per million gallons which it actually cost to dispose of sludge obtained by some of the other processes. The cost of sludge disposal is between two and a half and three dollars per million gallons of sewage. After filter pressing the sludge is carried down the bay on scows. That method would seem to be about as simple as possible. It would be simpler if they could carry the sludge in the wet form, but that is impossible, because if

mixed with the sea water in wet form it floats, whereas, when dried or filter pressed they can empty it in seventy-five feet of water and it will sink and cause no further trouble.

Langdon Pearse, M. W. S. E.: We are all indebted to Mr. Hatton and Professor Bartow for the splendid work they have done on the activated sludge process. In this paper, however, are a number of points open to discussion, on which an entire evening might be spent. Several matters, I think, should be emphasized.

Mr. Hatton's outline of the process is very broad, in fact so general that I believe it ought to be pointed out that the processes he has mentioned are not all on a par. For instance, he has compared screening with sedimentation. The comparison is not on an equal basis when the actual results are considered. There seems to be an impression that screening and sedimentation are on a par. Authentic results, to date, show that screening is much less efficient than sedimentation, in general. In comparing chemical precipitation with sprinkling filters or other biological processes, I think the members ought to bear in mind that biological processes can and do produce much better results.

It is somewhat unfortunate to suggest to engineers to disregard cost. If there is any reason for the employment of an engineer, it is to consider costs, and to produce the best results at the lowest cost—that is, the best results suited to all the circumstances.

Now, Professor Bartow, I think, has illustrated that point in comparing the cost of activated sludge disposal with attending sludge disposal conditions at Providence. Providence probably does not need an activated sludge plant at present to produce the results needed to keep the harbor clean. The total cost of what is done there may be justified, even though the cost of an activated sludge plant in that locality might not be high. That is why you cannot pick merely the cost of sludge handling alone and compare the processes. You must take the process as a whole and consider the costs of what you are trying to do to meet the situation in which you put your plant. In such comparison, fixed charges, depreciation, and operating charges should all be considered in arriving at a conclusion. Local financial conditions may also control.

Again it would interest many of us to know why the sewage should be treated by activated sludge at Milwaukee, when it is apparently so much cheaper to purify the water by filtration followed by sterilization and have pure drinking water without taking chances. Mr. Hatton touched on an interesting point when he spoke of the efficiency of water filtration as compared with sewage. I don't believe he realized the application of his remark when he made the statement. But it is very true that you can treat polluted water and produce good drinking water at a less cost per million gallons than you can purify sewage, even to a degree that is hardly safe to drink. That brings us around again to the point that an engineer must consider costs in studying such problems, if he is to arrive at the correct economic solution. Efficiency must also not be forgotten.

As the activated process is better understood and the details worked out, I feel that the process as a whole will be considered with more conservatism in its general application. It certainly requires very careful operation. Its costs are liable to be high, particularly operating costs. Watchful waiting is necessary at all times. The sludge is difficult to handle, being extremely watery. It requires concentration, preliminary to pressing or drying. On the subject of returns, there is also a question if all the cities in the country went into the business of producing low grade fertilizer, where the net income would land. On this point, however, I am assured by fertilizer manufacturers there is little to fear.

The most important thing yet to be accomplished is to reduce the cost of the air, because at present that is the most expensive part of the whole process. It is a point that impresses many cities that otherwise would consider the process, because they do not want to assume large operating cost. Many cities, particularly under special assessment laws, will assume a much higher first cost if they can obtain a much lower operating cost to produce a desired result.

In speaking of the efficiency of sprinkling filters in winter, in cold climates, I do not believe that engineers have sufficiently considered that under many conditions, possibly, a high degree of efficiency may not really be needed in a filter or other biological process in a cold climate, for the simple reason that nature has a most excellent refrigerating process operating in the streams. The engineer has usually collected winter samples and tested them in the laboratory under summer conditions which do not by any means obtain in the stream in the winter time. That has been recognized in a few eastern cities where the operation of biological processes is not required in the winter, the use of the settling tanks, for instance, to remove the suspended matter, sufficing to preserve proper conditions in the streams, where adequate dilution may be had. It is an interesting phase upon which we are working, especially, to ascertain the rate at which decomposition goes on under different temperatures. It is something that can well be borne in mind in operating plants in cold climates. The condition of the stream, its size, the presence and extent of ice, and the length of travel are factors which may, however, affect any conclusion to be drawn. Particularly in Canada where the small flow of sewage in a stream is liable to freeze up solid for many months below a town, it does seem a far extreme in sewage disposal to make a very pure effluent or attempt to in the winter time.

The only other point that I want to comment on is with reference to the bacterial removal. In many cases where bathing is concerned and the protection of water supplies, the question of bacterial removal may be important, particularly as a protective or temporary measure where water purification has not been installed. On the other hand, in stream pollution questions, the question of bacterial removal has sometimes been given undue importance, partly by the emphasis put on it by processes which have been mentioned by Mr.

Hatton, such as the electrolytic processes and chemical precipitation where there is a high bacterial removal and not necessarily a complete stability produced in the liquid. Now, high bacterial removal in a liquid containing much putrescible organic matter is only a temporary condition, for the liquid will again be seeded with bacteria in a stream and decomposition will set in, unless the organic matter has been stabilized. Sterilization is, therefore, usually only one of the incidentals in sewage treatment. It is important along the lake shores, and is particularly valuable at a place like Cleveland, where the municipal authorities are endeavoring to produce a clear effluent to protect bathing beaches and are not striving for a high grade effluent from the standpoint of stability.

In the problem the Sanitary District has at hand in the Stock Yards and Packingtown, the amount of air required is very much greater than Mr. Hatton or Professor Bartow have mentioned. We are using from four to six cubic feet of air per gallon of sewage, with a period of contact of about eight hours. We find that with the coming of cold weather that a considerable increase in the quantity of air is required to produce a fair effluent. We obtain a large amount of solid as sludge. It may interest you to know that by running a fine screen of about thirty mesh we remove actually six to nine hundred pounds of dry material to the million gallons of day sewage flow, and after the screened liquid passes through the tanks, we get two to three thousand pounds of dry material as sludge in the tanks. That will give you an actual viewpoint of the relative efficiency of the screen.

The activated sludge process is of vital interest to us because if we can treat sewage at, or in the immediate vicinity of its source, we can avoid a large expense in intercepting sewers and pumping, to say nothing of having the sewage much fresher. That leads to a point which I think well worth considering. If a stale sewage has to be handled, either on a sprinkling filter or in an activated sludge plant, unless extraordinary precautions are taken, odors may occur. Experience is, however, required to determine just where the line will come as to the dissemination of odor. At present it is remarkable that so little odor is produced in the plants that are operating with activated sludge, even where the sewage is strong and somewhat stale, as at Milwaukee.

Mr. Charles H. MacDowell: I have had some figures made recently in arriving at the value of the excrement per person per year. Our scientists report that figuring at ordinary commercial fertilizer values, the value of the excrement per person is about five dollars per year. In other words, we are wasting practically a half billion dollars of plant food yearly which the country sends to the cities. It does seem to me that in the interest of the people, and in the interests of the larger production of foods, as that question is becoming very important, we should seriously consider installing such processes as have been described here irrespective of immediate profit, so that we can return to the land that which comes

from the land and which it needs to feed our people. There is a big public interest in it beyond taking care of the health of the people who live in the cities. The city owes this duty to the country.

W. W. DeBerard, M. W. S. E.: What Mr. Hatton said about maintenance I want to emphasize again. Six years ago when I started in my present position, one of the topics I took up first with our New York office was the question of maintenance. At that time our water filtration plants were more or less in the same condition, although perhaps not quite so bad, as our sewage plants today. At the present time it is unusual to find a well designed water filtration plant left to run itself. The engineer who designed it sees to it that attendants are familiar with the operation of the various devices so as to produce better results with the plant than may happen to come from it with indifferent operation.

Mr. Hatton did not bring out one point which I have heard him make before, viz., that the very complex nature of the activated sludge plant will discourage the ordinary politician from attempting to run it. This means there are to be more places open requiring engineering technical ability

Dr. Paul Rudnick: I cannot add anything to what was mentioned about the plant at a previous meeting when Mr. Eddy addressed you. The results obtained simply substantiate what we obtained in our small tank in Chicago. We are now planning for a larger plant, a plant to take care of practically all of the Stock Yards and Packing House sewage in Fort Worth. These plans are under way now, but nothing definite has been decided on at the present time.

Mr. Hatton: May I just answer Mr. Pearse in one particular, because I think he received a wrong impression. I don't want it to be understood that I recommend the activated sludge process under all conditions. What I want to be understood is that where a non-putrescible, clear effluent is necessary, that the activated sludge process so far, has more promise than any other sewage purification process known. I realize, just as Mr. Pearse has stated, that it would be folly for a large number of municipalities in the United States to install the activated sludge process because it would be too expensive, that is, the character of effluent obtained in the activated sludge process is not necessary under the conditions of many municipalities, and it would be foolish to attempt to put it in. But where non-putrescibility and clarification are necessary I say it is the best so far available.

Now Mr. Pearse also asked me why, and it is a very pertinent question, why do we recommend such a high standard of sewage effluent in Milwaukee when we can purify our water very much cheaper than we could our sewage. That is true. Mr. Pearse states the question in a very true state. But Mr. Pearse forgets that we have three rivers coming down through Milwaukee, coming right through the residential sections, and the business section, and those rivers are in an absolutely vile condition. They must be purified.

And the first attack of the whole problem was to clean up those rivers. Now, we could not clean up those rivers without taking care of the sewage problem. We had no place that God has provided for us to dump the sludge. We have to provide for the sludge in some other way. We cannot take it out in the lake and dump it. That would be against public policy. Now, as we must dispose of the sludge the best thing to do is to make a sludge that pays us for its disposal. That answers the question of purification. If we must make a good sludge, and it have a value, we can just as readily make a clarified and non-putrescible effluent in obtaining the sludge and then the purification of the water can be accomplished by simple clorine treatment, as is being done today.

I want to answer another question which has been brought up very seriously to us this winter, and that is the very evident knowledge that we have that in winter time, of course, we do not require as much clarification or purification as in summer. That goes on very well until you get to an actual demonstration of the problem, as we have it in Milwaukee now. We are discharging no more sewage, or very little sewage in Milwaukee today in the river or in the harbor, than we were six months ago in the summer time. We are making a bacterial count of our water supply every day, five or six times a day. We have never had a larger count of B. coli in our water supply than we are having right now with the coldest kind of weather, with the water temperature down to about thirty-four to thirty-eight Fahrenheit. We have been having worse pollution today in the winter than we ever had in the summer time. So you cannot always depend upon the winter oxidization.

Professor Bartow: Two reports on conditions in Illinois rivers during the winter time have just been completed. When the Vermillion River below Streator was frozen in January, 1915, pollution was noted further down the river than it had ever been noted before, and large numbers of fish died. About the same time the Sangamon River below Springfield was frozen over, and large numbers of fish were killed for many miles down the river. This trouble was caused by the excessive sewage, the low flow of water in the river, which gave insufficient dilution, and the coating of ice which prevented the re-oxidation of the water and the destruction of the sewage. The cutting-out of the oxygen and preventing the fish from getting to the surface killed them.

And recently I have seen in the papers that similar conditions have existed this winter in the Sangamon River a number of miles below Decatur. Under ordinary conditions the sewage is oxidized before it reaches these lower stretches, and fish live there. When ice forms a covering over the river, the pollution is carried further down and these serious conditions arise. We must, therefore, plan for purification in the winter as well as in the summer.

Dr. Rudnick: The thought occurred to me during this discussion of the effect of low temperatures that in general we shall have to revise our notions of the limits of temperatures between which

bacteria thrive. We shall have to revise downward as well as upward. Every day the limits are being extended one way as well as the other. It has been found, for example, that the death point of certain bacteria is very much higher than we had ever supposed it was. It may go up practically to the temperature of boiling water. And so I presume the same condition will gradually develop as we go down the scale.

Bulletin University of Illinois, State Water Survey, series 13, 234 and 251.

IN MEMORIAM

ELMER LAWRENCE CORTHELL, M. W. S. E.

Died May 16, 1916.

Elmer Lawrence Corthell was born in South Abington (now Whitman), Mass., U. S. A., in 1840, the son of James Lawrence and Mary Gurney Corthell.

He was educated in South Abington High School, Phillips Exeter Academy, and Brown University.

In 1861, while a student in Brown University, at the first call for volunteers for the Civil War, he enlisted in the First Rhode Island Artillery, Battery D, and served through the war, attaining the rank of Captain.

In 1867, following the war, having completed his course at Brown University, he graduated with the degree of Master of Arts and with Phi Betta Kappa honors.

In 1894 he received from his alma mater the honorary degree of Doctor of Science.

In 1870 he married Emily Theodate Davis, of Providence, R. I., who died in 1884, leaving two children, Mrs. E. S. Dewey, of Gloversville, N. Y., and Howard Lawrence Corthell, a Civil Engineer, of New York.

In 1900 he married Marie Kuchler, of Berne, Switzerland, who survives him. He also leaves one brother, J. Roland Corthell, of Readville, Mass., and one sister, Mrs. Annie C. Phipps, of Wollaston, Mass.

It had been Dr. Corthell's ambition from boyhood to study for the Baptist ministry, but on account of health his physician advised him to select a more active profession and he chose Civil Engineering. He first entered the employ of Mr. S. B. Cushing, a prominent engineer of Providence, R. I., where he practiced and did field work in railroad, mill, dam, bridge, city, and other construction.

In 1868 he was appointed assistant engineer in the construction of the Hannibal & Naples R. R. in Illinois, now a part of the Wabash System.

In 1869 he was engineer in the location and construction of the Hannibal & Missouri R. R.

In 1870-71 he was chief assistant engineer, under Col. E. D. Mason, in the construction of the railroad bridge over the Mississippi River at Hannibal, Mo.

From 1871 to 1875 he was chief engineer of the Sny Island Levee, 51 miles in length on the east bank of the Mississippi River. During the same time, in 1873-75, he was chief engineer in the construction of the bridge over the Mississippi River at Louisiana,

Mo., for the C. & A. R. R. The draw span of this bridge was 444 feet long, then the longest draw span in the world.

From 1875 to 1880 he was assistant to Captain James B. Eads in the construction of the Jetties at the South Pass Mouth of the Mississippi River.

In 1880, while convalescing from illness, he wrote his "History of the Jetties at the Mouth of the Mississippi River," published in 1880 by John Wiley & Sons.

From 1881 to 1884, as engineer of the New York, West Shore & Buffalo R. R., he was in charge of the construction of that road and the extension of the N. Y., O. & W. R. R. to connect with the West Shore. During this time, he also assisted Capt. Eads and Colonel James Andrews in their plans for the construction of a ship railway across the Isthmus of Tehuantepec, Mexico, and from 1884-87 he assisted Capt. Eads in promoting the Tehuantepec Ship Railway.

From 1887 to 1889 he was associated in engineering partnership in New York and Chicago with George S. Morison, engaged in the construction of railroads, bridges, harbor and water works—among them being the Cairo Bridge over the Ohio for the Illinois Central R. R., then the longest steel bridge in the world; bridges over the Missouri at Nebraska City and Sioux City; two bridges in Oregon, one in Jacksonville, Fla., and water works at Bismarck, Dakota.

In 1889 he made examinations, plans, and report on the proposed improvement of the harbor at Tampico, Mexico, for the Mexico Central R. R. and later had charge of the Jetties as Chief Engineer.

In 1889 also he was President and Chief Engineer of the Southern Bridge & Railway Co., incorporated that same year to build a bridge over the Mississippi at New Orleans, and completed the plans and specifications for construction.

In 1889 and 1890 he was engineer of the St. Louis Merchants Bridge over the Mississippi, having charge of the design and construction of the substructure and foundations; also chief engineer of the improvements at the mouth of the Brazos River in Texas; also employed as a special consulting engineer in charge of terminal work in the City of Chicago for the Chicago, Madison & Northern R. R., a subsidiary corporation of the Illinois Central R. R., the C., M. & St. P. R. R., affording an entrance to Chicago from the west for the Illinois Central lines; and also in connection therewith for certain main and side track facilities for the A. T. & S. F. and the C. & A. roads.

In 1890 he made a personal examination between the Great Lakes and Quebec, Canada, of the question of an enlarged waterway between Chicago, Duluth, and other parts of the Great Lakes and the Atlantic Seaboard, and wrote a paper on this subject for the Canadian Society of Civil Engineers and the Western Society of Engineers at Chicago.

February, 1917

In 1891, on behalf of the Western Society of Engineers, engaged in solving Chicago's complicated railroad system, in Europe, he examined thirty-five railroad terminal situations; he also, while there, examined twenty-six harbors, to secure information for use in his work at Tampico, Mexico; and most of the subways from Glasgow to Budapest.

In 1897 he was again in Europe and made a study of many engineering works, some of the results of which were published in the Engineering Magazine in New York and London.

In 1898 he presented to the American Association for the Advancement of Science, in Boston, Mass., the result of two years' study in Europe on the past, present, and future of Maritime Commerce, showing the development of commerce in the next half century.

In 1900-1, in Buenos Ayres, he studied and reported to the Minister of Public Works on thirty-six different commercial problems which had been referred to him, and subsequently delivered thirty-six lectures in thirty cities of the United States and Mexico on his two years' work in Argentine.

Dr. Corthell was a prolific writer upon engineering subjects and his printed papers fill many volumes. He was active in the establishment of the civilian reserve corps of engineers. He was also an active participant, either in person or by important papers, in various international engineering congresses. At a meeting in Brussels, where all but six of the seventy-one papers were in other languages than English, he prepared for the Department of State, which had selected him as a delegate, a resume of the entire proceedings, making a volume of 245 pages. The success of the International Engineering Congress held during the Columbian Exposition was largely due to his work as Chairman of the Executive Committee.

After half a century of continuous work, Dr. Corthell found his chief satisfaction in the fact that his works have been beneficial to all forms of commerce, whether sea, river, canal, or rail, and that he had thus aided in reducing the cost of transportation on land and water for the benefit of all.

He was a member of a large number and variety of societies, having been President of the Western Society of Engineers in 1889, and his long and active life was devoted cheerfully and enthusiastically to the service of his fellow men and the achievement and up-building of the engineering profession.

Memoir prepared by John F. Wallace, W. J. Karner, A. F. Robinson, Committee.

EDWARD THOMAS HENDEE, M. W. S. E.

Died November 12, 1916.

Born February 22, 1880, at Claremont, N. H., died November 12, 1916, at Minneapolis, Minn., age 36. He was the son of E. J. Hendee.

Mr. Hendee graduated from the New York University in 1900 with the degree of B. S., afterwards receiving the degrees of M. E. and M. S.

He received the degree of Sc. D. at Columbia University in 1901.

From 1901 to 1902 he was Assistant Professor of Mechanical Engineering at New York University.

In 1902 he became associated with Joseph T. Ryerson & Son of Chicago as Advertising Manager. He built up and became Manager of the Machinery Department. He was made Assistant to the President in January, 1911. In 1913 he assumed charge of the Railway Supply Department of the firm. In 1913 he was elected Secretary of Joseph T. Ryerson & Son and continued so to his death. Under Mr. Hendee's management both the domestic and foreign machinery business, and the railway supply business of the company was very widely extended.

Mr. Hendee was Vice-President and Director of the Lennox Machine Co., and Director of the American Glyco Metal Company.

He was actively interested in engineering subjects and frequently attended meetings of the various engineering societies in Chicago.

He was a member of the Western Society of Engineers, American Society of Mechanical Engineers, Sons of the Revolution, Exemplar Lodge No. 966, A. F. & A. M., of Chicago.

In college he was a member of the Zeta Psi Fraternity and was recently a member of the Alumni Board of Trustees.

He was a member of the University Club, Chicago Athletic Association, City Club, Chicago Club, and Edgewater Golf Club. He was President and Director of the Edgewater Golf Club, and died on the last day of his incumbency as President.

Mr. Hendee was married October 12, 1907, to Miss Bessie E. Comstock, daughter of Mr. and Mrs. Edward Fitch Comstock. He leaves a widow and two sons.

Memoir prepared by Edward L. Ryerson, Jr.

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS.

Meeting No. 959, February 5, 1917.

The meeting was called to order at 8:00 p. m., by President Burt, with about 40 members and guests present.

The Secretary announced that the following had been elected to membership in the Society under the grades indicated:

Vincent Pagliarulo, Chicago..............Associate Member
Byron L. Kelso, Lincoln, Nebr...........Associate Member
Reuben A. Anderson, Chicago............Associate Member
Sutton Van Pelt, Chicago..........................Member
Thomas Wilson, Chicago...........................Member

and that the following had been transferred to the grades indicated:

Edward L. Ryerson, Jr., Chicago........Associate Member
R. P. V. Marquardsen, Chicago...................Member

He also announced the following applications for membership in the Society:

Joseph A. V. Turck, Wilmette, Illinois.
Richard J. Wynne, Chicago.
Theodore Doll, Chicago.
Harold L. Stevens, Chicago.
Frank J. Eckenfels, Moundsville, W. Va.
Willis Leriche, Chicago.

The President then introduced Prof. S. J. Zowski, Consulting Hydro-Mechanical Engineer and Professor of Mechanical Engineering at the University of Michigan, who read his paper on "Pitting of Water Turbines and Their Design," which was illustrated by lantern slides.

After the reading of the paper, it was discussed by Mr. W. E. Williams.

The meeting adjourned at 9:50 p. m.

Meeting No. 960, February 12, 1917.

This meeting, which was a patriotic meeting in honor of Lincoln's birthday, was called to order at 8:00 p. m., by President Burt, with about 150 members and guests present. The rooms of the Society were decorated with American flags.

Addresses on the Engineer Officers' Reserve Corps and the Military Training Camps were made by President Burt, Col. Charles S. Riché, Col. Julius A. Penn, Major Paul B. Malone and Mr. C. C. Saner.

Patriotic songs were sung during the meeting.

The meeting adjourned about 10:30 p. m.

Meeting No. 961, February 19, 1917.

The meeting was called to order at 8:00 p. m. by President Burt, with about 100 members and guests present. This meeting was intended to be the forerunner of the "Washington Award Meeting," which will hereafter be held in each year, on the third Monday of February, for the presentation of an honor award for engineers, established by Mr. John W. Alvord, and to be known as the Washington Award.

The program, therefore, consisted of five short papers on engineering work in Washington's time, as follows:

Surveying—Ernest McCullough.

Iron and Steel Industry—James N. Hatch.

Hydraulic, Sanitary and Municipal Engineering—Charles B. Burdick.

Roads and Pavements—Arthur N. Johnson.

Shipbuilding—John G. Kreer.

Previous to the reading of the papers, Mr. C. D. Hill, who was a member of the committee which reported on the method of administration of the Washington Award, spoke of Washington and the engineering work on which he had been engaged, and of the plan of administration of the Washington Award.

The meeting adjourned at 10:30 p. m.

Meeting No. 962, February 26, 1917.

The meeting, which was a joint meeting of the Electrical Section, W. S. E. and the Chicago Section, A. I. E. E., was called to order at 7:50 p. m. by Mr. T. Milton, Chairman of the Chicago Section, A. I. E. E., with about 100 members and guests present.

The Chairman then introduced Mr. W. J. Norton, who read his paper on "The Making of Rates After Valuation." The paper was illustrated by lantern slides, and the reading of it was followed by discussion by Messrs. L. K. Sherman, F. F. Fowle, P. Junkersfeld, Harold Almert, and A. C. King.

The meeting adjourned about 11 p. m.

E. N. Layfield,
Secretary.

BOOK REVIEWS

THE BOOKS REVIEWED ARE TO BE FOUND IN THE LIBRARY OF THE SOCIETY.

Èlements of Hydraulics. By S. E. Slocum, Professor of Applied Mechanics, University of Cincinnati. McGraw-Hill Publishing Co., New York, 1917. 329 pages, 6 in. by 9 in. Price

This is the second edition of a book that originally appeared in 1915. In the present edition, the author has used the terms "pressure of water," "flow of water," "energy of flow," etc., instead of "hydrostatics," "hydrokinetics," "hydrodamics," etc., which he considers an improvement, and he has also added to the text a more complete and up-to-date discussion of the flow of water in pipes, with special reference to the exponential formula and its graphical solution; a summary of the principal formulas for the strength of pipe; a more extended discussion of wier formulas; a fuller presentation of the modern use of siphons on a large scale; recent developments in the theory of water hammer; and the modern solution of penstock and surge tank problems. A number of minor changes have also been made and a complete set of answers to problems has been prepared, which is printed separately.

For those who are not familiar with the original edition, it should be said that the book was intended to be a modern presentation of the fundamental principles of hydraulics, with applications to recent important works, such as the Catskill Aqueduct, the New York State Barge Canal and the power plants at Niagara Falls and Keokuk. While the book does not go into turbine design, information is given in late developments, so as to enable the young engineer to make an intelligent choice of type and selection of runner. The book is divided into four sections, Pressure of Water, Flow of Water, Energy of Flow and Hydraulic Data and Tables, each of these sections being well subdivided, so as to present the subject in an attractive manner.

Wharves and Piers. Their Design, Construction and Equipment. By Carlton Green. McGraw-Hill Book Co., New York, 1917. 6¼ in. by 9¼ in., 248 pages. Price, $3.00.

The author states that he has written this book in response to an editorial in one of the engineering journals calling attention to the lack of American books on the subject. The subject of pile-driving has not been treated at length in this book, as it is already covered in other recent books, but the general question of design, construction and equipment, including machinery for handling miscellaneous package freight, has been systematically treated. The author is of the opinion that there is a tendency at the present time to slight the advantages of timber construction and unduly magnify those of reinforced concrete.

The contents of the book are as follows:

Chapter I. Introduction.

- Definitions.
- Requirements.
- Types.
- Materials of Construction.

Chapter II. Primary Principles of Design.

- Commercial Life.
- Growth of Ships.
- Marginal Wharves vs. Piers.

Dimensions of Wharves.
Live Loads.
Tidal Prism.

Chapter III. Details of Timber Construction.

Piles and Pile Driving.
Lateral Support for Piles.
Test Piles and Borings.
Details of Construction.
Iron and Wood Fastenings.
Sewers in Piers.

Chapter IV. Retaining Walls for Piers and Marginal Wharves.

Function of Walls.
Calculation of Pressures.
Gravity Walls.
Relieving Platform Walls.
Sheet-Pile Walls.

Chapter V. Piers.

Comparison of Types.
Pile Platform Piers.
Block and Bridge Piers.
Solid Filled Piers.

Chapter VI. Wharf and Piers Sheds.

Sheds in General.
Fire Resisting Construction.
Framing.
Side Coverings.
Roofing.
Lighting and Ventilating.
Doors.
Protection Against Damage and Accident.
Examples of Typical Sheds.

Chapter VII. Equipment of Wharves and Piers.

Fenders.
Mooring Devices.
Wharf Drops.
Pavements.
Railroad Tracks.
Fire Protection.

Chapter VIII. Cargo Handling Machinery.

General Considerations.
Classification and Description of Machinery and Appliances.
Loading and Unloading Ships.
Freight Handling on the Wharf.

Appendix. Cost of Walls, Piers, Sheds, etc.

Walls.
Piers.
Sheds.
Miscellaneous.
Index.

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Passenger Terminals and Trains. By John A. Droege, General Superintendent N. Y., N. H. & H. R. R. McGraw-Hill Book Co., New York, 1916. 9¼ in. by 6¼ in., 410 pages.

This is a companion volume to the author's well-known work on freight terminals, and is worthy of a place with it in the railroad engineer's library. The contents are as follows:

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Vol. XXII MARCH, 1917 No. 3

INDUSTRIAL DEMOCRACY WITH PARTICULAR REFERENCE TO THE RELATIONS BETWEEN CAPITAL AND LABOR

By George Weston, M. W. S. E.

Presented December 4, 1916.

My study of the relations between Capital and Labor has convinced me that no lasting or satisfactory benefits can be derived by either through a continuation of present conditions, and, as our country is the melting pot for the nations of the world, so are such bodies as ours here to-night, collectively, the crucible for refining of opinions and molding of principles which finally are found to be the bases in all constructive legislation.

Hence this paper is presented for the purpose of bringing out a most liberal discussion of the subject, particularly of the fundamentals and recommendations contained therein, with the hope that it will have its influence in bringing the representatives of Labor and Capital into a more satisfactory and harmonious working relation for their own mutual benefit and permit the operation of our public utilities uninterruptedly for the accommodation of the public.

This subject is one of leading importance today. It has length, breadth and thickness, and is one closely connected with the work of an engineer for, as a rule, the consummation of his endeavors means the investment of capital and employment of labor. This fact holds true whether it be in connection with a private enterprise, a limited partnership, a manufacturing corporation or a public utility company, and, therefore, to my mind, is of special interest to engineers.

It is desirable in all branches of industry to substitute co-operation for strife, and for Capital and Labor (employer and employed) to work together for their common good, to co-ordinate their efforts into collective action in the pursuit of their mutual well being, and for each to understand and assume his full obligation to the public. This paper, however, will be directed principally to public utility companies upon the basis of service to the public, and fairness and justice to all concerned.

The subject of improved relations between Capital and Labor

has been discussed at great length, but usually from extreme partisan viewpoints, with Labor and Capital arrayed against each other.

Hostilities between Capital and Labor is unjustifiable and wrong. It is founded upon the theory that the interests of one are antagonistic to the interests of the other, and therefore, there can be nothing common between them; a theory erroneously fostered and encouraged and seemingly taken for granted by the rank and file. This is a false doctrine because their interests are similar; at least they are not antagonistic. Justice can be done to both Capital and Labor without warfare.

There are two sides to the question, Labor and Capital, and they both are entitled to fair treatment, but up to the present time frequent and serious disagreements have arisen resulting in riots, strikes, destruction of property, and the forcing of increased wages without considering its effect upon the income accounts of all parties affected or "higher cost of living," or the general economics of the country, all of which are disastrous, and in the end the public pays the bill. The conditions attendant upon this situation are becoming grave and must be corrected to save our country from business and financial failure.

I am a champion of the rights of labor. It should receive its just reward and in full measure. I am opposed, however, to a one-sided system of forcing a selfish principle upon others by threats, mob law or otherwise, without care as to its effect upon their neighbor, the public in general or the economic questions of the nation.

The necessity for a public utility is the need of some class of service to the public, and this requires capital investment and the work of labor skilled in the different branches necessary to create the property and operate it, and both should receive a fair return for its service; but neither Capital nor Labor should be permitted to exploit the property for unreasonable gain or for the exercise of objectionable, coercive union or political power.

Capital should not be permitted to pile up huge profits at the expense of underpaid labor. Capital and Labor should be partners in the business, each receiving its fair return from the net profits.

When Labor understands that it will be placed upon a footing equal to that of Capital, that there will be no aristocracy of Capital growing unjustly rich from the fruits of their labor, but instead that there will be one great democracy of interests building up a great public utility to serve the people and that each worker and each contributor of a dollar to Capital investment will be treated alike and receive his just and fair portion of the earnings, then the present general feeling of jealousy, dissatisfaction and unrest will disappear and harmony and general good feeling will be restored.

My connection with public utility matters for many years has caused me to give this subject thought and study, and at the time of the street and elevated railway strike in Chicago, June, 1915, I compiled the following fundamentals:

(1) Capital and Labor are dependent one upon the other.

(2) Capital cannot be successfully employed without the help of Labor and Labor cannot be profitably employed without the assistance of Capital.

(3) From this fact it seems most fair and equitable that each should participate fairly in the results of their joint efforts.

(4) This principle should be the fundamental economic basis upon which to consider the relations between Capital and Labor.

(5) Then the two chief elements necessary to create and operate a public utility have the same fundamental interest in properly performing the obligation to the public assumed in the franchise of the public utility.

(6) This obligation should be inviolate in principle and good service to the public should be the first consideration in the operation of a public utility property.

(7) The obligation to give good service to the public falls upon Labor as much as upon Capital. Consequently, all legitimate and fair operating expenses necessary to give good service must be considered, as well as all reserve funds necessary for the upkeep of the property or other franchise obligations, before any increased division should be made to Capital or Labor.

(8) After having fulfilled all franchise obligations then any remaining earnings should be disposed of upon some fair basis to the benefit of both Labor and Capital.

(9) It would be unfair to increase the share to Capital beyond a reasonable return upon the investment and not increase the return to Labor, and it would be unfair to increase the return to Labor by reducing the return to Capital below a reasonably fair amount.

(10) From the fact that service to the Public should be the first consideration of any public utility it should be unlawful for the employes to conspire to "strike" or the employers to conspire to "lockout."

(11) It would seem that either a National, State or City court or Board of Arbitration should be established by law, to which body should be referred all matters of dispute between Employer and Employes that cannot be settled between themselves, and this should be accompanied by a law making it a penal offense for employes to conspire to "strike" or for employers to conspire to "lockout."

The above fundamentals are based upon a viewpoint of fairness and impartiality and this will inevitably lead one to the belief that the interests of both Capital and Labor are identical in character —that their obligation to the public is similar and that the laws under which they work and act should be such that no harmful results to the general public can occur and that the means are provided and assured for fair treatment to both Capital and Labor.

The recent steam railroad crisis has again brought this subject to my mind, impressing me with its increasing importance. The

hurried passage of legislation without thorough and careful consideration and analysis depicts the menace that accompanies present conditions.

It is certainly a grave situation when the brotherhoods of steam railway employes have the power to call a strike and tie up every steam railroad line in the United States with the consequent paralysis of business and great financial loss and injury to the general public and to have it possible for them to stampede the President and Congress into the passage of hasty and questionable legislation.

Such legislation does not cure the evil, but acts only as a temporary estoppel of the exercise of mob law and to falsely encourage the labor leaders into believing that their strike tactics are justifiable.

Our country is essentially one of industry, and industrial success requires the co-operation of capital and labor—a co-operation based upon fraternalism instead of strife and discord. We must extend scientific management to include at least the necessary wants of the workman and his family in the beginning of his period of labor and make it possible for him to increase his earnings in the future in accordance with his individual growth and advancement so he can provide more of the pleasures and advantages for them.

Industrial democracy includes many factors and its ramifications are far reaching. In addition to those specifically touched upon herein are the following that I will mention—and these are not all:

High wages.

High cost of living.

Assurance of the more capable man in the more responsible position.

The top must be recruited from the bottom.

Unity of action for the common good.

High wages should mean maximum output.

High wages with minimum output means "high cost of living."

It often becomes necessary for persons or people to be protected against themselves, and I am herein recommending forced arbitration and legislation to prevent by law, strikes or lockouts. Not upon the basis of attacking either Labor or Capital, but to prevent them from conducting warfare based upon erroneous principles that in the end only tend to tear down and disintegrate, and substitute for them principles of justice and fair dealing, which latter will endure forever.

The strong arm of the government should be used not in favor of one side or faction but impartially in favor of the general public for its general good. In the words of our great Lincoln—"Government of the people, by the people, for the people."

Much time and effort has been spent in the past to enact legislation to control Capital—"Combination in restraint of trade;" "Concentration of capital;" "Railroad pooling," etc.

Our Interstate Commerce Commission is now engaged in a very extensive investigation of the steam railroad public utilities of the nation, including their valuation; the latter to establish fair investment values as a basis of determining fixed charges and a fair return to capital in rate making. Included in the other items of expenditures mentioned to fix rates is the one of wages. Is it fair to the general public to exact legislation to control one element of rate making and tolerate unlimited organization in another element, and to use its united power by threats and coercion to accomplish its selfish ends, to create riot, and conditions akin to civil war, in direct opposition to the principles of the Constitution of the United States, the opening paragraph of which reads as follows:

"We, the people of the United States, in order to form a more *perfect union, establish justice, insure domestic tranquility, provide for the common defense, promote the general welfare, and secure the blessings of liberty to ourselves and our posterity,* do ordain and establish this Constitution for the United States of America."

A division of net earnings between capital and labor (employer and employed) is commonly referred to as "profit sharing," and, in the cases of smaller corporations and partnership businesses that have adopted the principle is variously apportioned; in some instances a bonus based upon percentage of sales, or a percent increase upon the annual wage or some other basis of division mutually satisfactory.

With large corporations and public utility companies where profit sharing has been adopted, various plans have been pursued from merely recognizing the principle through the establishment of "old age pensions," Christmas gifts equal to a small percentage of the annual wage, to the apportioning of a certain per cent of the gross income to regulate the total return to labor, as in the case of the Philadelphia Rapid Transit Company, which, several years ago, instituted the principle of "profit sharing," apportioning 22 per cent of the gross to labor. Other corporations in addition to adopting direct profit sharing, encourage the purchase of stock in the company, so that the employes become part owners of the business. Where real profit sharing has been adopted its beneficial effects upon the relations between employer and employed have been marked. The workmen take a personal interest in developing efficiency measures that lead to economies and better service to the public.

"Profit sharing" as it has been practiced in the past differs from "industrial democracy" as advanced in this paper in the sense that the initiation of "profit sharing" and its discontinuance has been optional with the employer, while industrial democracy applied to public utilities, as intended by this paper, means that along lines to be fair and equitable to all parties, capital, labor and the general public, the continuity of service to the public shall be regulated by law, nationally to the extent applicable, and by state and city legis-

lation to the extent necessary, and that the character of service, rates, and the distribution of gross earnings shall either be regulated by law or supervised by a board or boards of control established by law.

It is not the intention of this paper to provide for the millenium or to discuss details, but only general principles to the extent necessary; to point out the practicability of "industrial democracy" as herein outlined applied to public utilities, and that these principles are in accord with the Constitution of the United States; and that it is the duty of the public officials created by law, particularly the law-makers, to command what is right and to prohibit what is wrong, and to take the "middle of the road" in dealing with the subject and go straight through to the end without fear or favor.

With large public utility companies the following basis of "profit sharing" offers a simple method of adjusting income distribution so that capital and labor will each receive its just share.

It must be conceded that the wages of labor at the present time in the United States are high by comparison with any previous time in its history, or with any other nation, and therefore present wages can be taken as the minimum return to labor and be used as a fair basis for future pay-rolls to be charged to operating account or be readjusted from time to time as the limitations of the gross income may require. (This gross amount allowed to labor for future pay-rolls should be distributed between all classes of labor upon the basis of value of service rendered, the skill required, the hazard with respect to life or limb, etc.) The total amount thus paid will establish the percent of the gross receipts paid to labor.

It is also necessary to have determined what is a fair percentage of return for capital, including sufficient to care for extra hazards of the business and corporate organization expense, etc.; this, together with general operating expense, including taxes, renewals, any other necessary reserve funds, franchise obligations and the establishment of a cash working reserve, should be first deducted from gross income, and the residue, if any, divided between labor and capital in the proportion that the total percent of gross paid in wages to labor bears to the percent of "fair return to capital."

Many other dispositions of surplus earnings in the interest of both capital and labor could be arranged and worked out in detail to cover the general principle or to fit any particular case. The above is simply an example.

This is a subject of vast importance and ramification and vital to the peace and prosperity of the nation, and I commend it to this society as one affecting the interests represented by its members, the business man, the professional man, the artisan, the laborer and the people of the United States in general, and that the strife between labor and capital, under the general present conditions, is the greatest menace the nation faces today.

DISCUSSION.

Ira Dye, ASSOC. W. S. E.: One often hears it said that labor and capital derive benefit from the same results, and can, therefore, have no fundamental quarrel. It requires only a few years of actual experience as one of the molecules composing labor to convince any man that this identity of interest does not exist in the social organization with which we, in nineteen hundred and sixteen, are dealing. It may have been true when master and apprentice worked in the same shop, ate the same food, and lived in the same house. It is not true today that the desire of the owner and that of the worker are reducible to a common denominator. They are not commensurable.

Modern industry is founded on the charter by government of bodies corporate. In theory the government of these corporations is quite democratic—or, let us say, representative. Even in practice, it is true that corporations obey the expressed wish of their stockholders, as voiced by ballot or through their directors. The stockholders want dividends. Give them the regular, and a few extra, dividends, and they will send in proxies and ask no questions.

Now a surprisingly large number of financially successful men think that it pays to hold down wages of the workmen in their factories, on their trains, etc., until these workmen actually refuse to go on at the old rate. This produces an absolutely appalling quantity of discontent, and, more tangibly, slowing down of production. Probably some managers know this. Every workman knows it and nearly all do it. Why do these men deliberately waste all the time they can? Simply because they know from experience that extra effort will not be rewarded, at least, not until they strike! There will be men who deny this. Let them take a hammer and chisel and go into the shop and chip castings for sixty days, and they will know it.

I shall not say there is only one way to bring about industrial peace and boost the human efficiency of our mines, mills, railroads and factories. I may say, however, that there is one way to do this without shock or expense—it will pay for itself. Let every corporation in America beat its employees to the strike by giving the inevitable raise in wages in the form of stock in the corporation—fractional certificates, perhaps. Let every labor organization counsel and urge its members to put their savings into the securities of the employing companies. Make it easy to do so by taking the stock out of the hands of jugglers of prices—a little at a time, as the employees take it up. Elect a labor man or two on the board of directors and put a few of the director's sons in the shop or on the trains.

The plan is not new, in the idea. It is new only in insisting that the policy must be as widespread as the corporation, as a business machine. It would make the interests of employe and company identical for the first time. It might put some highly conspicuous brokers into producing instead of gambling activities. But when the company wanted money for a new shop or some new rolling stock, the directors could know that there would be no danger of the mort-

gage being foreclosed or the stock sold at a discount, provided only that they managed the company honestly and really needed the money! Every share they took off the market by selling it to an employe, for labor, would be one less share to turn up in alien hands at the election of directors!

I have personally discussed this matter with hundreds of men with dirty hands, and skilled hands, too, as well as with a rather large number of men who sit in at the mahogany table on meeting days, and not one has told me the scheme would be unfair or impractical. As engineers, and I claim to be an engineer in the making, it is up to us to get into the controversy between our two prime tools, labor and capital, and make them into one doubly useful automatic machine. If I am wrong, I want to hear from anyone who thinks I am; if I am right, why don't we get out a specification and call for bids on a campaign to get this question settled?

C. W. Balbridge, M. W. S. E.: The relations between labor and capital as usually discussed refer to the relations between labor organizations, or unions, and their employees, and many people do not differentiate between the rights of a laborer as an individual and the rights of labor as an organization.

This is particularly true of the members of the labor organizations themselves. They are very ready to claim the benefits derived from organization, but very loath to accept the responsibilities which must go with the act of organization.

Any person who will consider the matter calmly and without bias must realize that no large organization, whether of labor or capital, can be permitted to exercise powers which they do not possess as individuals, or individual ownership in the case of capital, and at the same time claim and exercise the rights and exemptions enjoyed by the individual.

Not many years ago but few laws were in existence for the government of organizations of capital, and, owing to political influence, governing bodies were slow to act, until the unfairness of big organization so aroused the public that the legislative bodies, even though in fear and trembling, were forced to enact laws to afford relief.

To the present time, through fear of the voting strength of the labor organizations, legislative bodies have failed to pass any laws for the proper guidance and control of the power and strength of the labor organizations.

The recently threatened, and still menacing, railway strike, is serving to arouse the public to the fact that organized labor is not the only part of the body politic which has rights, and while no one wishes to deny the laborers their rights, the public has a paramount right to insist that organized labor shall not enforce its rights to the great detriment and inconvenience of the much greater number.

It is, therefore, incumbent upon the public to insist that laws

be passed to prevent needless injury upon the many, and to provide a means whereby the laborers may secure their rights by orderly process and without needless injury to others.

There is now in existence the unit court, provided for the trial and proper disposition of the cases of individuals who are accused of breaking the rules or laws enacted for the protection of society.

There are also the two-sided courts, in which duly authorized judges hear civil cases. In these courts any individual who has suffered wrong at the hands of another, may have that other summoned and through orderly process have the wrong investigated and righted without interference with the rights of others.

It is now probably time to extend the system of courts to a three-cornered or three-sided institution wherein such cases as labor disputes may be fairly heard.

A three-cornered or three-sided court would be necessary, since in most such cases the interests of the laborers on one hand, and the interests of the employers on the other, are no greater and frequently of less importance than are the interests of the public. Therefore, a court providing for the fair and orderly hearing of the rights and claims of all these parties interested must be provided.

Any suggestion for the passage of laws for the government and control of labor organizations always draws bitter opposition from the leaders of these organizations, but such laws must and will be passed for the rights of the public at large are paramount to those of any body of citizens whatsoever, and if government and civilization are to endure, such laws are imperative.

Instead of opposing the creation of an orderly process for the settlement of organized labor disputes, the members of unions should take a leaf from the experience of capital and endeavor to mould such legislation fairly, instead of opposing it, until the public becomes aroused and causes the passage of adverse legislation, as has happened in the case of the railways.

The most frequent and the most strenuously asserted argument advanced by labor organization against any regulation is the insistence that any law which would prevent a person from quitting his job at will is industrial slavery.

This argument holds good when applied to the individual, but is not applicable to an organization, and if laborers want to gain the advantage accruing to organizations they must also accept the disadvantages which go with such organizations.

No one wants to deny any individual the right to quit his job at such time as he sees fit, provided it is a bona fide action, but there is a very clear distinction between a bona fide quitting of a job and a strike or walkout. Neither does any fair-minded person want to deny to any employer the right to discharge any individual employe when his services are unsatisfactory, or to lay off his forces when their continual employment means an actual and serious loss to him, but such an action is also clearly different from a lock-out.

It is very important that laws providing for the orderly settlement of labor and wage disputes and kindred questions between labor and capital be passed soon, and most important of all, that they be fair to all parties interested, for none of us know in which corner we may belong next year.

There is one other thought which I want to mention, and that is that in the minds of many people, labor organizations are right. We continually hear the expression that labor organizations are right and that they are doing wonderful things for their members.

If this is true, why should we leave them to the necessity of fighting for everything they get? Why make it necessary for them to lose time and pay and inflict punishment upon themselves and the public in order to inflict sufficient punishment upon their employers to enforce their demands? Why not provide by law an orderly process for securing their rights, without inflicting the loss upon themselves and others which is necessary through the present process?

There is no more reason or justice in permitting it to be necessary for the labor organization to get in a physical fight, in the nature of a strike, to secure their rights, than there would be for leaving our citizens to fight out their personal disagreements, over boundaries of property or such matters, without recourse to the courts. There is, in fact, much less reason, for fights between individuals would rarely inflict loss or damage upon very many others who are not concerned, while fights between organizations usually inflict greater punishment upon the public than upon the parties to the fight.

It seems to me that it is time that some laws were provided for the orderly and proper handling of such cases.

George A. Schilling: It affords me more than ordinary pleasure to be here this evening and listen to this discussion, because I regard the engineers as the pioneers of all modern activity. Whether in war or in peace, you are the men that span the rivers with bridges and cross the mountains. Your activity tends to bring communities closer together, and make all the nations of the earth neighbors. And yet, I regret to say that, among all the professional men and all the various citizens in their different walks of life, there are less engineers who are conspicuous in the public mind with regard to discussing and considering the relation between man and his fellow than can be found in any other calling. Now, why is it? I have thought of this since this paper was handed to me. I am acquainted with many of the engineers. I have been in the city hall, and they are splendid men. I have great respect for them. But when it comes to discussing industrial and social problems, they are as a rule silent. Now, is it because as a rule your activities are employed by municipalities, by public service corporations and large corporate interests that tend to make you men more silent than you would be if you were in some other profession? I don't know. I rather think myself that it sort of dampens your courage because you are employed by those great interests, and great interests do not encourage the dis-

cussion of those questions in a fundamental way, because to do so might disturb the *status quo.*

Now, I am delighted that Mr. Weston has opened up this question. He entitles it Industrial Democracy, but finally concentrates on the public utility service, whether of the city, the state or the nation. I do not know how he finally would work out the details as to how much should belong to capital and how much should belong to labor, whether he intends to set aside all of the other expenses before he deals with either and gives either their reward. But let me tell you, when a man has a wife and five or six children, he cannot very well afford to first let you put aside all of the incidental expenses, the depreciation, the misfortunes that may happen, and then finally find that there is very little left, so little that his wife and his children can neither pay the rent nor subsist. So that, when you come to consider the question of capital and labor in the concrete, it seems to me that you have got to get down to something of a more fundamental basis than simply the profit sharing, or the question of simply saying in general terms: "Let us try to be just to each."

Now, what have been the evils of the public service corporations? The evils have been in the stock jobbing. To be plain, let me just cite an instance well known in the history of Chicago. Charles T. Yerkes knew a great deal about organizing and running the street cars in the streets of Chicago. He was a remarkable man. He was a general of the first order in his line. But he also knew how to run a street car through the common council and the legislative body of this state. And if it was necessary to spend hundreds of thousands of dollars in order to successfully railroad it through the council or the legislature of the state he was willing to pay the price.

Now, that suggests the idea: what shall we do with the public service corporations? Shall we leave its situation as it is today, doling out franchises as we have been doling out, or shall we revolutionize our method? Within the last two years I have been reading Frederick Howe's book on European Cities at Work. Mr. Howe was an alderman in the City of Cleveland when Tom Johnson was elected mayor. Howe was a Republican alderman, but he liked the policies of Tom Johnson so well that he voted with Johnson on all his policies. And when his term was out the Republicans refused to nominate him; and Johnson nominated him and re-elected him. He is now the commissioner of the Immigration Department of the national administration. He is a remarkable writer. He has written four or five books that appeal to the profoundest students of social problems. One is "The City, the Hope of Democracy." And you all know that the thinkers and speakers as a rule have said in years past: "The city is the despair of republican institutions, and that if ever the free institutions of the United States will be overthrown, it will be because of the vandals that we generate in these cities." Howe sounds the other key: "The City, the Hope of Democracy." And I

want you all to get this book and read it, because he analyzes the whole mechanism of the municipality just as an anatomist does the human body. And he shows the sources from which the corruption comes, the maladjustment of all these utilities. He then advocates that the public utility should be owned by the community.

Now, there are a great many thinkers who also say that it should be operated by the community. There I draw the line. I think that the community ought to invest the necessary capital, but that they should as a rule be operated by public service corporations that simply bring together the necessary skill to operate, but not the necessary capital. Employ your engineers, your motormen, your conductors, let them all come together, and then Mr. Weston's idea can be carried out splendidly. Then they are simply operating under long-term or short-term contracts; they would tell the community what they were willing to furnish service for, but not to invest a cent. That part of the business ought to be the community's.

But the subject, when we deal with industrial democracy, is much larger. You are all younger than I am—at least, I think so—and you will find that in your lifetime these questions will become hotter and hotter. And it is not because the working people want to be disturbers, and it is not because capital with premeditation and forethought wants to exploit everybody, but it is due to the relationship in which both of these elements find themselves, each acting according to impulse. And the result is you have the confusion that you have, and you have got to employ your brains in studying out a more harmonious relation for the employment and activities of both capital and labor.

The questions are here now. In the State of California, at the last election—there was nothing seen in the press because the presidential excitement overshadowed everything else—but in the State of California the single taxers there this past election cast something like 300,000 votes on the proposition that all taxes should be eliminated from every species of property except a tax on land values. They cast something like 300,000 votes on that proposition.

I am a single taxer, and I view the whole industrial situation from the standpoint of the doctrines laid down by Henry George. That will bring industrial democracy, and in my judgment nothing else will, unless you take the socialistic side of it, and it seems to me there are several very serious objections to that. Because you cannot regulate all human activities and get all of the benefits out of human effort by the mere enactment of laws. Because all laws are rigid, and what we most want in human life is flexibility, mobility. It seems to me there is where all of these endeavors that want to regulate everything by law fall down.

Secretary Glackin, the secretary of the Board of Local Improvements, came to me before I left the city hall—he being a senator—and he said: "Schilling, what should I do on the eight-hour law for women?" which was then pending. "Well," I said, "do as you please about it, but I don't like to regulate the hours by law." I said:

"Now, take the trade union movement of Chicago, particularly in the building line. They get together with their employers, and they make a contract for so much per hour or per day, and they stipulate in that joint agreement that Saturday afternoon shall be a half holiday, but that if the employer is pushed and must have their time, he shall pay time and a half; and that if he is still further pushed and must have their services on a Sunday or a holiday, he must pay double time." I said: "There is the automatic principle. If the employer must have this work done he is willing under pressure to pay the extra cost. But just as soon as he does not have to have it done, automatically they get their half holiday on Saturday and nobody asks them to work on Sunday." I said: "Mr. Glackin, there are seasonal occupations. Take, for instance, the time of the year when there is a great rush on the Christmas trade and the employers want to supply the demand and there is great need for both men and women in these shops to work longer hours than ordinary. If you pass a law that they can't work more than eight hours, why to that extent you deprive that man of the opportunity of supplying the market. In that respect the trade unions have got any statutory enactment shoved clean off of the boards, because they regulate it by the automatic principle: 'If you want us pay us extra. If you want us on Sunday pay us double time. If you don't need us we don't want to work more than five days and a half in a week." "Why," he said, "I never thought of that."

And so it is with all of your endeavor in trying to fix and circumscribe all of the human activities in the industrial world by statutory enactment. You make it rigid. It is not mobile. It becomes like a brickbat, and you have got to get a sledge hammer and break it to pieces and smash it if you want to get out from under it. I concede that the public service employees belong to a different class. There are men who belong to the single tax movement who go so far as to say not only that they are a class within themselves, but they think that the government ought to own all of the properties of public service companies and then disfranchise all of the employes. Because they say they would hinder the other citizens from getting a square deal. I do not go that far.

But, suppose Mr. Weston's idea should be incorporated into law, that the public service corporations in the City of Chicago came together with their employees and make some kind of an agreement among themselves. Now, we have in the traction service alone, I think, about ten or twelve thousand employees, and they are pretty live wires. They get out on election day and they do some tall hustling. I know them personally. I know what they could do, together with these stockholders that are deacons in churches, and influential members of different clubs.

Are you quite sure, Mr. Weston, that if those two elements could be brought together on some terms mutually agreeable to themselves, that the public would also be fairly included in their considerations? How are you going to fix that law so that the public

is not going to get left? It is a very complicated question. I think the solution of it in a more simple form is along the lines which I have intimated, that the community itself should be the owner of the utilities, furnish all the capital, and that it should be operated by a private company supplying the service for so much.

I think if we had been wise enough we could have owned all of our public utilities without scarcely costing us a cent. I have been for over eight years associated with the Board of Local Improvements in the special assessment department. We pave streets, build sewers and sidewalks, and lay water mains, and we charge the citizens whose streets we thus improve what it costs, on the theory that the land values increase as much as the improvements cost. Now, there is none of you here but what knows I am telling the truth when I say that when the Board of Supervising Engineers is urged by the City Council to extend its tracks five or ten miles in some of the outskirts of the city, that immediately as soon as it is found out that the street car lines are to be extended, land values rise equal to the cost of its construction. And had we been wise enough in the beginning, we could have saddled all those expenses upon the land so improved to which conveniences were brought, and which we brought within the circle of civilized life.

But public utilities are modern things. When our government was formed there was not a mile of railroad in the United States. There was not a gas main, water main, sewer, telephone or telegraph anywhere. There was not any of these things which modern invention has brought to the world which have revolutionized the whole status of human relationship.

When our government was formed there were three million and a half of people in the thirteen colonies. Today, you can go to the City of New York, and stand at the Court House, and within a radius of twenty miles there are more than twice as many people living there than there were in the entire original thirteen colonies.

I simply relate this to show you we are a new civilized being by reason of all these great improvements which have come to the world within the last ninety years. I am glad that Mr. Weston, through this awful strife between capital and labor, has been stirred up to such an extent that he sat down and wrote this lecture. And I am satisfied that he would not have thought of writing it if those men had not turned loose and raised Cain.

But the employees of public utility companies are not the only things that we are up against. You all recall the two great anthracite coal strikes that threatened to paralyze the commerce and the industry of the United States, when Roosevelt had to even threaten J. P. Morgan, who wanted the President to call the military and declare martial law. He said: "If you don't settle this strike within so many hours, I will declare martial law; I will take possession of the mines and the railroads, put the miners to work, and see to it that the people who need anthracite coal are going to get it." And Morgan settled the strike.

We are up against a new situation, and we have got to use our gray matter in trying to solve it. I think when the European war is over, there will be such a disturbance in each of those countries, that we, by seeing what they are thinking about, will take hold of the same problems.

Recently I read an article by Northcliffe, the owner of the Times and a number of other daily papers in England, in which he said: "I have been at the trenches. The men there are building up a new England. They are talking about many things. But," he said, "there is one thing upon which they are all agreed, and that is, when they come home the land of England shall belong to the people of England and no longer to a privileged few." That is what the European war is going to do. By stress of circumstances, sacrifice and the great law of necessity, they are going to solve these problems along more equitable lines. And I hope we will be wise enough and good enough to follow in their footsteps.

F. H. Bernhard, ASSOC. W. S. E.: This subject being so broad, as is very manifest by the remarks of the preceding speakers, it is better, it seems to me, in order to reach any conclusions, to limit the discussion to the object of Mr. Weston's paper, which was to take up public utility corporations.

In that connection it should be noted that during the last eight or nine years we have had a very great change in regard to the status of the public service corporation. The former control, or rather lack of control, that was in vogue, has been replaced by the conception that the public is a very necessary and important element in all public utility service. That conception has manifested itself in the passage by many of our states of public utility laws which are enforced and carried out by commissions or boards that presumably make a special study of the requirements of public utility service in its various features.

Now, to my mind, since these commissions have come to be well established and are being established in other states from time to time, that are enacting this legislation, and since these commissions are empowered in most of the states to deal with practically all elements of the general problem of public utility service, they might just as well be given a little bit further authority without very elaborate legislation. I believe that they should have the authority to fix not merely rates and pass on matters of stocks and bonds, but also to act as arbitrators when it comes to a question of differences of opinion between the public utility and its employees. It seems to me that this is only a perfectly natural and logical development of the public service regulation idea and that it affords a very simple means of solving the frequently vexatious problem of the relationship between the public utility and its employees.

I think most people who have considered the subject are agreed on the stand that Mr. Weston has taken in his paper, which shows a very fair attitude throughout. The employees of a public utility, being engaged in quasi-public service, do not have the same broad

prerogatives that are possessed by the employees of a mason or other contractor putting up a building, or the employees of any other industrial or commercial concern; but since public utility service is something that is necessary, as well as useful and convenient, since the public needs it as well as desires it, they are bound to render this service. As one of the speakers has said, they, of course, have the privilege of quitting individually, but quitting in a body and thereby hampering the public is an entirely different matter. So it seems that this entire matter of the public service corporation and its employees is not only a vital problem, but it is on a different basis from the very much broader aspect of the relations of capital and labor in various industrial and mercantile businesses.

A. J. Schafmayer, ASSOC. W. S. E.: The subject tonight is based on such broad, fundamental principles that there is a temptation to discuss a great many extraneous subjects. But, of course, it depends on these fundamental relationships, and, naturally, they must be considered.

In the first place, we all look at this question according to the way we consider those fundamental relationships. For my part, I am a regular reader of Public also, and I would much prefer the single tax to the co-operative industrialism which seems to be looming on the horizon.

But, to get down to the application of these principles to Mr. Weston's specific proposition, I would go along with him in harmony until we come to his seventh premise, in which he states that the obligation upon labor is equal to that of capital. And there I would not agree with him. I should say the obligation is not equal, because capital invested in such enterprises has received a specific benefit in being the recipient of a monopoly due to the public grant of franchises authorizing the use of the land. Then, because this is a monopoly, any attempt to strike by the labor element will bring about a disturbance of our social affairs. That is, if it were not a monopoly, there would be no such imperative reason why labor should not strike, because then that would not completely tie up our affairs. Due to the fact that we have conferred a monopoly upon the capitalistic side, we have put a weapon in the hands of labor also, but we have not conferred a like benefit on labor. An employee can be discharged, but stockholders are not subject to discharge. Any stockholder of the capital can sell his stock in the public market, but any laborer cannot sell his job. Any stockholder can go into the courts and demand an accounting if he thinks he is not getting a fair deal or a fair return, or any group of bondholders, although they may be only a minority, may go into the courts and request an accounting or demand a receivership. At least, they can get a hearing upon their demand. But a laborer cannot do that. Then, for these reasons, I would not agree with Mr. Weston in his tenth premise that the strike should be made a penal offense. He said the obligation to the public is similar. I will agree that it may be similar, but it is not equal in degree.

Then, his plan provides for a division of the returns above the fixed items which he has outlined in these latter paragraphs, and the basis of it rests upon the present conditions for labor, and upon a fair return to capital in interest. Now, of course, there have been Supreme Court decisions on what a fair return should be. But in passing that, if we guarantee to capital a fair return, then that should be made much lower than if it is not guaranteed, but is placed upon a speculative basis. Those, however, are details to be considered later. But he did not mention a third party there, which should be always considered—capital, labor and the public. And if there is a return over the division of this surplus to capital and labor, there should be a similar division to the public in reduced rates, or in amortization funds, or increased service.

There is an interesting feature that comes in here, as we conjecture on how this would work out, which I want to mention, and that is, that Mr. Weston proposes to regulate this by law. In that case he gives the right to labor for such a company a standing somewhat as a commodity, would not an employee thereby receive a vested right to his position with the company? That is, supposing a man, or a group of men, were working for a company, and by collective bargaining or unionism, they agreed that they were not getting what they wanted, or were entitled to, perhaps under the law they might be able to demand an accounting or demand a receivership for the company and see whether they were getting their rights. And again, if you establish this by law and allow the public to have a legal right in the corporation also, why could not any taxpayer or patron at some time, if he thought the business was not being managed properly, or that certain of the large stockholders had voted themselves exorbitant salaries, or something of that sort—why couldn't any taxpayer demand an accounting or receivership to see if the thing was being run on a proper basis?

And in that way, it will open up a great many possibilities that require very careful consideration, before the plan is adopted.

Murray Blanchard, M. W. S. E.: The author speaks of recommending enforced arbitration. I cannot understand how there can be such a thing as compulsory arbitration. When an arbitration board is appointed, it is one's privilege to avail oneself of the opportunity to bring matters of dispute before it, but as the word implies, this is a matter of discretion. This point came up recently in the threatened strike, when the railroad employes refused to arbitrate. I would like to know if it is possible to have such a thing as enforced arbitration.

Mr. Schilling: They do it in New Zealand.

Stafford Montgomery: The author refers continually to the strike and the lockout as being independent happenings, whereas, the lock-out is merely the means of defense from a strike. If the strike were prevented, it would be necessary to legislate to prevent the lockout. In the same way, if murder is to be prevented, it would not be necessary to prohibit the employment of capital punishment.

In connection with the profit-sharing proposition, you have something that seems to me, upon analysis, to be entirely impracticable. As soon as you begin to weigh one manufacturer or one public utility corporation against another and allow for the amount of water that has been injected into one and the amount of milk that has been removed from another, you have a condition in which the return on capital would be something less than zero in one case and a very fair return in another case, assuming you have fixed wages. If you are going to divide the surplus above a legitimate return to capital, among the employees, that practically means an increased wage scale in certain sections. In the case of two roads paralleling one another, one might be conservatively financed and the other might not, and it would be simply out of the question to pay the employees of one road double the wages of the employees of the other road.

The same thing would apply in manufacturing corporations. One automobile manufacturer may, through a combination or circumstances and ability, succeed in paying enormous dividends when he is buying material at the same price, or buying labor at the same rates as other manufacturers, who fail. Now, if you are going to fix rates for labor in the automobile business by the available surplus for distribution to the employees of the most fortunate automobile manufacturer, you simply give him a monopoly of the automobile business, because no one else could manufacture automobiles at all. But, on the other hand, if you are going to fix wages for employees in the automobile trade in proportion to the capital and the returns on capital of some of the companies that failed, you will find that some of the employees would have to be paying a penalty for working for the automobile manufacturer

The whole proposition of profit-sharing is so utterly mixed up that it seems hopeless to do anything with it. The thing, however, that is of some importance for the time being in connection with the disputes between capital and labor, is the element of restriction of output. About five years ago, I spent a year in sociological work, and one of the principal features of my research was ascertaining the attitude of labor leaders on that and other general economic questions. And there was one point where I found almost absolutely uniform opinion, and that was the output had to be restricted. That was the one fundamental principle that they all seemed to agree upon. The theory on which they based their argument was, of course, fallacious, but it does not make any difference whether the leaders believe it or not as long as the doctrine was dealt out to the rank and file. If they followed it, it was immaterial as to what the mental process of the leader was. The rank and file believed that if half the men in the world became twice as efficient, the other men would be out of employment, and that, therefore, it was the duty of every conscientious citizen to do just half as much work as he is able to do, so there would be just twice as many jobs.

Warren R. Roberts, M. W. S. E.: Mr. Weston has not, as he re-

peatedly said, tried to work out the details of this problem, but to present the general principles. I agree thoroughly with the setting forth of the main argument in this paper, and I have perfect confidence that in due time it will all be worked out by our people. I am not one of those who are pessimistic about the coming conflict between capital and labor in this country. We have always been able to solve our problems in the past, and I think that the people are just as competent as they were in the years gone by. The fact that a busy engineer will take his time to study this question, as shown by this paper, shows the spirit of the times.

Mr. Schilling has presented one thought that I would like to reply to. First, I think the Society is greatly honored in his presence with us tonight. He is a man of very broad learning and culture and has given years of thought to this question where we have given minutes, and I was glad that I had an opportunity to hear him.

While I think the suggestions that he made regarding engineers who work for corporations has perhaps some slight foundation, I believe the real reason why engineers are not heard more in public on all questions is because we are too busy with the things at hand. I know that there is a great deal every day that I would like to do, but I do the things that are nearest. They seem, at the time, to be the most important.

I am not an engineer who works for any public service corporation, or any other corporation. I have worked for myself practically all my life. But I am heard no more in public, I am no more public-spirited than any of those who are working for such corporations. We are busy and do not feel that we have time for these things. The politicians and public men have the time, and that is why they are heard so much more than we are.

E. N. Lake, M. W. S. E.: I once heard of a man who apologized for writing a long letter because he said he didn't have time to write a short one. I think the fact that Mr. Weston has put into this paper six pages what our President has said would ordinarily occupy six hundred pages, is an indication that he has spent a great deal of time and thought on this subject.

A great American engineer once said, as we were looking at one of the historic cathedrals of France: "The engineer has done more for the advancement of civilization in the last hundred years than what this cathedral stands for has done in the other eighteen hundred years of the Christian era." We have here, as indicated by this paper tonight, an engineer who is combining what the cathedrals stands for with the work of the engineer.

Mr. Weston: Mr. Yerkes' doings in our midst have been referred to. I wish to say that I am glad that that reference was made. It gives me the opportunity of calling to your attention the fact that the very lines of railroad that Mr. Yerkes exploited in his great financial workings, have, since the year 1907, been under the supervision of a board of engineers that regulate those properties, and it is no longer possible for financiers connected with them to exploit

them. They cannot add anything to capital account but what is actually an improvement or betterment to the property, and it is approved by this board of supervising engineers, in connection with which I have the honor to have been associated since its inception. That illustrates to you gentlemen that all these great questions of finance, of operating expense, the relation of the laborer to the capitalist, are susceptible, in my judgment, of solution, and solution along reasonable, permanent, practical lines.

Mr. Schilling remarked that he thought that the municipality, or the Government, should own the public utilities. That may be the correct principle, and it may not. He further stated that he thought that the operation of the properties should not be in the hands of the Government.

With respect to his first statement, about the ownership being in the hands of the Government, I see no difference in the net result, whether the capital that is invested in that property is governmental, state or municipal, or whether it is owned by the general public, unless it be that in the beginning of time, the Government undertook to own the utilities, and by special assessments from time to time, and year by year, it would be possible through direct or indirect taxation (and not be too burdensome upon the public), to raise sufficient money to create our public utilities free of debt without injury to the general public or individual. I believe that today it is impossible immediately to undertake any such cash investment by Government funds. If the Government should take over the railroads, it would be necessary for them to assume the debt obligations. The Government with its great credit might be able to borrow that money at a less rate of interest than the individual, but the same operating expense, including interest, would come out of the public as though it were a privately owned utility.

In answering that one question, I think that I can answer a number of remarks or questions that were directed at my method of a fair rate of return to capital and labor. Rates are supposed to be assessments upon the public to pay for the transportation, we will say, of merchandise, or passengers—in the case of railroads, or a rate applied to provide for the cost of producing lights in a lighting company, or to produce a commodity that the individual public utility is supplying to the people. It is just as easy to include all the items of expense in determining what is a fair and just rate as it is simply to take a few. Those who have been obliged to study the question of public utility operating expenses, which includes all those items, renewals, taxes—everything that is necessary to support a public utility, know that they are susceptible of almost exact pre-determination, particularly from year to year, or from period to period. We are getting more expert all the time through our efficiency engineers.

For instance, the city makes out a yearly budget in advance. Every railroad corporation makes up a yearly budget in advance. It would be just as easy for a supreme public utility supervising body to make these estimated income account statements in any

adjustment of rates or question of dispute between capital and labor. This question, gentlemen, is an important one. It is necessary, in my judgment, to have these regulating bodies. They should be composed of men of integrity, men of high grade and standing in proportion, we will say, or in comparison with our Supreme Courts. When there is a difference of opinion between labor, we will say, and capital, instead of the laboring man being required to demand of his employer that he raise his wages, and then threaten if his wages are not raised to strike and paralyze the business, the disputed question should be submitted to a court, a body composed of men of integrity, men that the country will have confidence in, whose rulings should be supreme with respect to that one particular thing—it is their duty to go into the analysis of it in its entirety. I say that is possible. We will start, you may say, with our poorest laborers—any man who has a family is entitled to a wage that will permit him to support that family, at least to provide them with the necessities of life. And I say that it is possible for a body of intelligent, educated men of affairs to go into all these questions and establish, if you please, what would be a minimum wage for any man that is employed by a corporation, particularly a public utility. I believe it is possible. And the more I study this question the more I am impressed with the belief that the principle is sound. If it is possible to start with the minimum, it is certainly reasonable to build up and determine what is a reasonable wage, according to the service that a man renders.

I do not believe that anybody can question the fact that any public utility should be entitled to earn its operating expenses. If they are to serve the public with a necessity the public should pay what is reasonable, right and proper to produce that service.

Every man who has a dollar that he has saved, that he wishes to invest, when he invests that dollar, he expects to have something in return for its use. And that is an economic principle that is fair. It is right. He should receive a fair return for that dollar. That establishes the fact—I do not believe anybody can question it—that capital is entitled to a fair interest, we will say, to start with.

Now, any corporate organization cannot get along just with the interest that it pays upon its investment, because there is Mr. A and Mr. B and Mr. C, away up into the thousands and hundreds of thousands of our citizens that invest their money in these public utilities. They are the people that get the four per cent or the five per cent or the six per cent, or whatever is paid out by the corporation on its securities. Now, in addition to that the corporation has corporate expenses. They cannot carry on their business without additional expense—corporate expense that they must take care of. Consequently, in addition to the ordinary four per cent or five per cent that capital receives, the corporation is entitled to an additional return to take care of its corporate expense.

Some reference has been made here tonight to the income account deduction and that if all these charges are to be taken out

first and let labor come in at the end, why, there will be nothing left of labor. I think you are a little wrong about that because it was my purpose, it was my intention to make it plain that the laborer was to get his minimum first, which he generally does, because he gets his pay from month to month and week to week, or semi-monthly, and if at the end of the year there is not sufficient to pay interest or pay taxes, there is a deficit and the company may go into the hands of a receiver. Therefore, it is necessary to have determined what is a fair percentage of return for capital, including sufficient to take care of the extra hazards. Some businesses are hazardous. I shall not enumerate them now. You all know that some businesses have extra hazards. Provision must be made for corporate organization expense, general operating expenses including taxes and renewals. All engineers, and particularly those that are associated with public utility property, know that the renewals, the maintenance of your property, not only repairs, but the replacement of worn out parts must and should come out of the earnings of the property. That is, the property should be permitted to earn sufficient to pay for these renewals. And then the necessary franchise obligations. Public utility companies operate under franchises they receive from the government, national, state or municipal. Oftentimes these governments in granting this monopoly, or this privilege, provide that they must pay certain stated amounts—the city of Chicago, for instance, receives 55 per cent of the net receipts from the surface lines. In addition to that they have to pay for sprinkling and sweeping the streets, and many other expenses. Those are what I call franchise obligations. They must pay them. Consequently, the people must pay a rate that is sufficient in amount to permit them to pay all of these items of expense.

And the establishment of a cash working reserve. Now, we all know that in the past that business has gone along by year to year by comparison in waves. We have a wave of good times, and we call that a "fat" year, and our credit will go up. Then we will have a period of depression, and our credit will go down. Now, it is necessary in any well regulated business to have a cash working reserve which will be built up out of the "fat" years in order to take care of the deficiencies, the deficits of the "lean" years. Now, that is in favor of the laborer and wage earner just as much as it is the capitalist who looks for his 5 per cent on his dollar that he has invested. If you are going to protect everybody, then you must require this cash reserve, and it is just as important—more to the interest—more important to the laborer that there is a cash reserve established during the "fat" years to take care of the pay roll and all the other expenses during the "lean" years.

Now, I say that this should first be deducted from gross income. You must do that. That must be paid. You must take that out of the gross earnings, and the residue, if any, divided between labor and capital in the proportion that the total per cent of the gross paid in wages and labor bears to the per cent of fair return to capital.

Now, when I was talking about the return to labor I used these words:

"It must be conceded that the wages of labor at the present time in the United States are high by comparison with any previous time in its history, or with any other nation, and, therefore, present wages can be taken as the minimum return to labor."

And that establishes the per cent that labor receives from the gross. It is not a hard problem. Now, if you just stop to think a little while and put a little time on this and analyze it a little bit, it is really a simple proposition to work out. It can be done. It is not an impossible task. I believe it is easy. And it can be done upon a fair and equitable basis to all concerned.

Mr. Montgomery, in his remarks, it seems to me, rather talked about the conditions that are attendant upon the smaller manufacturers. I do not know as I mean to say smaller. He referred particularly to the automobile manufacture. Now, I have said in the beginning of my paper that co-operation is better than strife in all industries. I have applied this paper to public utilities, for the reason that I believe that they should be regulated by law. They are more susceptible to regulation by law, for the reason that they are public utilities, and serve the public whom they must depend on for a franchise. They must go to the public to secure a license to operate, to do business, to serve. And I say it seems to me clear that a public utility is the one that we should go after first and try to clear up their difficulties before we undertake to go beyond that to the individual manufacturer. I do not think that our present conditions attendant upon the smaller manufacturers are so bad that we need worry particularly about them.

There is one thing that seems to me plain—I do not see why it is necessary to talk very long about the point without everybody agreeing about it—and that is that the continuity of service to the public from the public service corporation should be protected in some manner so that the people will not be deprived of that service that is so essential to their comfort and wellbeing. For instance, electric lights—imagine the inconvenience in case of a strike and no lights at all. Would we go around as they did hundreds of years ago with tallow candles and similar expedients to take the place of the electric light? I say that it would be wrong to inflict that injustice upon the public. It is the same with respect to water, or transportation. It is vital to our needs that we can go out at a certain time in the morning and be almost assured within a very few minutes of time of taking a car and being carried to our place of business. If there is anything that occurs to interfere with that, then the whole business organization of the city is disrupted. And I say that that is wrong and it should be protected by law. It should be prevented.

Now, when we take that away—when we take that club away—(we term it a club because that is what it is)—when we take away from the laborer the privilege of striking to enforce what he thinks

are his rights—we must insure to him that he will have fair treatment. And, therefore, I say that in addition to controlling the continuity of service, that the distribution of the income account, which will include the division of the gross to the wage earner, shall be regulated by law also in some manner. I believe it can be done. I believe that it makes no difference whether the property is municipally owned, owned by the government or owned by private individuals. The same rule applies. And taking the present situation I do not conceive how it is possible to change that condition by the government or the municipality owning the property, because they certainly would have to assume the debt obligation and pay to the owner of the investment his interest just the same. And the property would be required to earn that interest, and you would have everything except probably taxes, which might not be exacted. If you did not exact taxes from that part of our gross it would have to be provided in some other way. Mr. Schilling thinks that the single tax will fix all that. Perhaps it will. But in the end, in the great economic analysis of our financial interest of the country it will not make a farthing's difference, because your corporate expense will be just the same and you will have to raise the money from some source, and if it does not come out of this pocket it will come out of that. It will make no difference in the end. So that probably the first thing then to determine is what method are we going to apply to remedy existing faults? We have with us now our present conditions. They are susceptible of improvement. As stated above, ownership, in my judgment, is not a governing factor. Let us get right to the meat of the proposition now. You can apply it under present circumstances just as well as you can if the properties are owned by the government or by the municipality or by the general public.

Mr. Schilling: You regard the activities of the public service corporation with its franchise and its capital invested as applying to a distinctive class in itself and, therefore, that we are justified in proceeding by law when to proceed in other activities might be an open question?

Mr. Weston: I believe, as I have set forth in the paper, that the necessity for any public utility is to render service to the public. It requires capital to create the property. You must employ labor to operate it, as well as employ labor to create it. You cannot hoard your money and create a property, you must spend it. You cannot bring in your labor without capital and create your property. One is dependent upon the other. I say that they should be partners in that business, that capital should not be permitted to pile up huge profits at the expense of underpaid labor.

I say that the man that builds the engine and the man that runs the trip-hammer, the man that collects the fares, the man that makes it possible to operate the institution, is entitled to his proportion of the earnings. Now, I am not saying this on the principle of

socialism. I say that that is simply the natural right of the worker. It is applicable under our present conditions.

Now, if I understand Socialism properly, the theory of the Socialist is that the products of nature belong to the public, that the machinery to produce should belong to the public, that this machinery should only be used to produce what is required for consumption, and not for sale for profit, that the product from this machinery should belong to the individual worker. Now, I am not working along that line at all. I am not theorizing on that at all. I am talking of our property that exists today as it is protected under the Constitution of the United States, that it is owned collectively by a great army of our citizens that have saved their money and put their dollars into that property. They are entitled to a fair return upon that property. They are entitled to it until it is returned to them in some manner, either out of the earnings of the road or by somebody else purchasing it or the government taking it over. They will be protected under our Constitution. Let anyone try to take it away and you will see the lawyers flocking into court, and the man that comes and can prove that he is the owner of that property will be protected under the Constitution of the United States, and to change it you will have to change our Constitution. There is no use in turning away from the fact as it exists today. These are fundamental facts.

Now, I say that the laborer, the man that does the work, that makes it possible for that capital to earn money, is entitled to his proportion of the profits. Now, then, in rate making you must make the rate so that the man can earn his fair proportion. I do not see how your municipally owned property or your governmentally owned property, if it is to be operated by private individuals, changes the problem one iota. If there is any item of expense that is left out, why that is left out, and you have the rest to consider, and your problem is just reduced by that item, one or more, whatever it is. If you have no taxes, you take that out. If the government, in some legerdemain fashion, can create the money necessary to buy all this, and can hand the money over to the individual —the billions that we have (I do not know what they will do with it when it is handed back to them without some avenue of investment) under those conditions we might save the interest out of the earnings, but the general public loses that part of their income.

Another item of expense would be removed. But when you get through you will have certain items left. You may eliminate some of them by government, state or city ownership, but you have your problem just the same, I believe. Isn't that so, Mr. Schilling?

Mr. Schilling: To a very marked degree.

Mr. Weston: Isn't it so? If it is to a limited degree then it must be so. You know that as engineers we have to deal in facts— two times two is four—it is or it is not. We cannot temporize. It must be either one thing or another. We either have it or we have

not. Now, that is the way that we analyze things. Now, that is so; it must be so.

You do not cure the evil by municipal ownerships, I believe. You may simplify it some, but you still have the problem.

E. N. Layfield, M. W. S. E.: Mr. Weston, I would like to have you go a little further into one point that has been touched upon. I think I know what your answer is, but I would like to hear what you have to say.

Suppose, for instance, that it is determined by a competent body or board, what the proper return is on the capital invested, and what the proper rate of wages is. If the returns to both sides were to be determined on the theory that they are to get nothing further, that might result in the lowering of rates to the public. Does your proposition contemplate that rates are to be kept high enough to create an intentional surplus to be held before each side as a spur to better and better endeavors, or do you only propose to divide such surplus as may exist after rates to the public, rates of wages and rate of return on capital are determined? In the latter case, the surplus may, of course, occasionally be a deficit.

Mr. Weston: I would say this in reply to that question, that rates are based upon—should be based upon—what is necessary to produce the service, which includes proper wages and a proper return to capital. Now, with a fixed property—that is, a fixed investment with a given rate of interest—the interest part of that problem is a fixed amount. It does not require any further figuring. Now, in order to determine what the taxes are, we have the records. We can estimate very closely if the general public demand is going to increase taxes, we can figure on the safe side of that. I don't mean to figure experimentally at all. But you can determine, in my judgment, what is a fair estimate or apportionment of the different items that go to make up the operating expenses of the company, including a per cent to be agreed upon of the gross to go into a cash reserve. Now, the public are interested in the service that they are going to get. The public should not be required to pay anything more than what is right and fair for the service. At the present time the rates that are established, of course, include wages and all other expenses. And after you have paid all those expenses at the present time the net profits go to the company. In some instances, I think, the net returns are exorbitant. They are too high. In other instances they are too low. There is, in some cases, a deficit. Now, where the earnings for a given public utility are so high that the labor, for instance, is getting more than it should get for its service, and capital is getting more than it should get, the public can come in and demand a reduction of rates. And this court would be obliged to consider a demand from the public for a reduction of rates just as promptly as it should act upon a demand from either the laborer or the capitalist for an increase. I have stated in my paper that along lines that are equitable to the three interested parties—labor, capital

and the general public—that those matters shall be adjusted by law. I think that it can be done. If the general public concludes that they are being taxed too high, why they can ask for a reduction of rates. "What are you getting out of this?" "I am getting so much." "Well, you are getting too much. We will have to cut you down." That will result in a reduction of rates. It seems to me that it is as simple as can be. The public, of course, shall be a party to all this.

Mr. Layfield: Yes, but the particular point, Mr. Weston, that I had in mind was this: Suppose that you determine with reasonable accuracy what the return should be to capital, and what the returns should be to labor, and suppose that that should result in reducing, say, a street car fare from five cents to four cents.

Mr. Weston: The public gets the benefit of the cent.

Mr. Layfield: Would you reduce the fare and divide only such incidental surplus as might occur, or would you allow a real and intentional surplus to be created for division as an incentive to better effort on the part of both sides? The incidental surplus might occasionally be a deficit.

Mr. Weston: Now, the idea of the working reserve is to provide in the "fat" years, a fund to take care of deficits in the "lean" years. If there are no "fat" years and your income does not give the proper reward to labor and the proper reward to capital and pay the other operating expenses, then it is evident that there should be an increase in rates. And I say that the public should be perfectly willing to pay a rate that is sufficient and proper to take care of these necessary items. Does that answer the question?

Mr. Layfield: Well, yes. The point that I had in mind was whether this surplus that is to be divided was merely a surplus that results from probable inaccuracies in estimating the costs or whether it was an intentional surplus that is to be divided as a reward and as an incentive to better efforts.

Mr. Weston: We read every day about "melons" that are cut and distributed to the shareholders of these large corporations. Now, I say that if there are any large earnings that way that they should be distributed not only to the shareholders but to the laborers, and a good large proportion of that should go into a sinking fund, or cash reserve, to take care of the conditions. For instance, we have all heard of some corporations that are earning fabulous profits. Now, I say that the laborer is entitled to share in that profit. And there should be a cash reserve established in some manner to take care of the lean years.

I believe that when we do get into an analysis of this subject we will conclude that it is absolutely necessary to limit the charge, that the steel corporation, for instance, can charge for its output. Now, I can cite for you things here that I know that there are certain items that a year or two ago we were buying, we will say, for $2.55 where we are paying $4.95 for the same items now, that

are manufactured out of steel. Now, you can either take it or leave it. That has the effect of raising prices. It keeps our prices up. Now, it matters not whether this product is sold abroad during the war. It is possible, when we get into analyzing this, that the steel corporation should have been prevented from raising their prices to such exorbitant heights, because it reflects right back on our own market and our own cost of production. We have to suffer accordingly. Now, I question whether it is right or proper for these corporations to be permitted to raise prices in an unlimited manner in the way they do. I did not intend to get into that tonight because we had enough to talk about without. But all these questions will come up, and they are susceptible of solution and correction, in my judgment.

Now, in public utility corporations we hardly ever deal with the production of commodities. We suffer with the rest of the citizens, that we are obliged to buy those commodities, but with public utilities as a general rule they do not supply manufactured commodities unless it is electric light or things of that nature. Of course, we have railroads, their commodity is the service that they furnish. I mean that they do not furnish actual tangible merchandise. But I question the right of the public in general to permit these large corporations to at will raise prices and make huge and tremendous profits. I question the correctness of that principle. I think it is all embodied in the great economic question that is before us.

E. N. Lake, M. W. S. E.: That last statement, Mr. Weston, answers one of the questions that is in my mind. You have defined the public utility as a public necessity. We will all admit that there is nothing more necessary to our life than food. From the principles that were set forth tonight it seems to me the ultimate conclusion, the ultimate development, is their application to the farmer, the packer, the commission man and the grocer.

S. E. Bates, ASSOC. W. S. E.: That brings up an angle of the subject that I was a little surprised had not been touched upon tonight, namely, the "value" of the American dollar, as it is often termed. To begin at the beginning, this method that has been outlined by the author may serve as a means of allowing wages to fluctuate down as well as up. For the past twenty or thirty years, wages have constantly been going up. So has the cost of living, and the price of steel, and, in general, everything else that we pay money for. Now, these things are all related. And it all hinges upon the fact that essentially, the basis of American currency, the dollar, the gold standard, is not a logical one. If we took twenty leading commodities and averaged those we would get a unit of value, a dollar, which would be a stable unit or more nearly so than that expressed in terms of gold, which is not stable. The rise in price of wages, and the corresponding rise in the price of food and other things merely represents a depreciating value in the "price" of gold. i. e., the "price" of a dollar.

W. W. DeBerard, M. W. S. E.: Mr. Layfield raised the question as to what to do with the extra cent when you are making too much money. In Cleveland, if they make too much money they give transfers; if they are not making it, they do not give transfers. That kept things evened up. It seems to work out fairly well in Cleveland. They do not carry the thing along from year to year as we have been doing. When you get $17,000,000 piled up in the City Hall, as at the present time, it creates a temptation few politicians can resist. They want to spend it in almost any old way just so it can be put into circulation again.

Mr. Weston: With respect to the seventeen or eighteen millions that you have just referred to, I believe that there is open to the city an avenue of expenditure for that money that will provide for the public a very much needed source of relief to our present desperate condition of burdened transportation. I believe that the public will receive the benefit from that eighteen millions in full.

Mr. DeBerard: It was more in reference to the Cleveland plan, that is, of fixing rates every month, so to speak, that I had in mind.

Mr. Weston: Well, I question the practicability of the application of that method here. I would think it would be better to have a fixed standard of fare. When it becomes apparent that that income is insufficient to give the proper service, in some manner there should be some source of expenditure cut off, or the rate should be raised; or vice versa, if we find we are earning too much money, then we should make a permanent reduction in the rate. I believe that the cash reserve is a feature that will take care of the fluctuations in a more substantial manner. I don't believe, however, for some time that we will suffer here from having too much income.

I can say a few words with respect to the subject that was mentioned a few minutes ago, and that is, I question very seriously the practicability of utilizing any of the income from transportation for any purpose except transportation. In other words, if we have any money to spend, give it to the people in improved service until such time as our service has become ideal, if that is possible. And after you have accomplished that, why then consider the question of reducing the rate. We have a long way to go in this city, like every other large city, before we can get our transportation facilities so that they can be termed ideal. And, in my judgment, every dollar that is earned on a public utility or on a street railroad, we will say, that is not necessary for the purpose of upkeep and paying labor and paying for the interest on the money you have borrowed—that money should go into service to the public, and not, for instance, be put into pavements. I question whether the riders should pay for the pavement, or should pay for sweeping the streets. I think it is better to put on more cars and give them better service and extend your lines. That is the reference that I made to this eighteen million dollars, that it would be put into an improvement and an extension of our service so that the people would receive better service.

RELATION OF PUBLIC UTILITIES TO THE PUBLIC

By W. W. Freeman.*

Presented at a Joint Meeting, Electrical Section, W. S. E. and Chicago Section, A. I. E. E., January 31, 1917.

It is comparatively easy to define the proper relation of public utilities to the public, but very difficult, under present conditions, to produce such relationship in actual practice. The difficulty arises not from serious difference of opinion as to what relations ought to exist, but more to misunderstanding on the part of the public as to what the conditions today really are. In other words, mere terminology offers little opportunity for disagreement, but in the execution of admittedly correct theories of operation there is constant opportunity for misunderstanding and dispute.

The time has gone by when any intelligent public utility operator asks to be regarded in any other light than that of public servant with all that such term properly implies. We freely concede that the primary excuse for the public utility is the need of the public for the service which the utility is created to render. If such service is rendered efficiently and honestly, the utility is a distant benefit to the public and is entitled to be recognized as such. It is furthermore to the interests of the public to guarantee to the utility every possible support and advantage to the end that the service rendered shall be the best possible and shall at all times be thoroughly dependable. There is thus a mutuality of relationship which cannot be ignored or restricted without detriment to the interests of both parties. The primary obligation on the part of the utility is that the service shall be first-class and the rates reasonable and, on the part of the public, that these conditions being met, no restrictions shall be imposed which make it impossible or difficult for the utility to perform its proper functions.

Upon this outline of what we may term axiomatic principles, there is probably little disagreement in any quarter. The difficulty arises principally in the fact that partisans on both sides claim that the opposing side is unwilling to intelligently and impartially ascertain the facts governing the cost and character of the service, and be bound by them. Again the ascertaining of the facts is in most instances much easier than it is to get the facts clearly before the public. This, we may believe, is not due so much to the unwillingness of the public to learn the facts as to the difficulty on the part of the average individual to satisfy himself as between the various conflicting claims made on all sides in the press and on the street. The speaker thoroughly believes that the public utilities generally are keenly alive to their full measure of responsibility to the public and are anxious to have the public know this and have true and full

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knowledge of all of the facts which bear upon their proper relations. He believes also that a majority of the public are equally sincere in a desire to acquaint themselves with the facts and deal fairly with the public utilities according to their idea of justice. If this be true the future of the public utilities is secure if they can satisfy the public of their sincerity and capacity, through such avenues of information as may be taken advantage of for the enlightenment of those who wish to learn the truth concerning public matters.

The secret to the securing of public support for public utilities consists in arousing the enlightened self-interest of the public to a realization of the fact that only a prosperous public utility can serve the public satisfactorily and acceptably. A financially impoverished utility cannot serve the public acceptably any more than an unnourished servant can do good work for his employer. Starvation wages never produced a good output for any employer and it is as invariably true that a public utility, living from hand to mouth, is unable to give first-class service to the public. This matter goes deeper than the mere question of wages and food. Every thoughtful person realizes that an employer who is constantly criticizing his men, without just cause, or who permits others to do so, is thereby reducing the efficiency of their work and injuring his own interests. Correspondingly, a public utility which is subjected continually to criticism and abuse from thoughtless or malicious elements in the community is thereby prevented from rendering to the public as loyal and efficient service as it could otherwise do. If it were more generally understood that unmerited criticism and misstatements circulated in a community against its public utilities can only tend to impair the service to the public, there would be less toleration of such critics on the part of the public and everyone, perhaps including the critics themselves, would be benefited thereby.

These observations lead to the thought of outlining certain conditions which ought to be guaranteed to public utilities by the public which they serve, in order that the service shall be adequate and satisfactory at all times.

Prefacing these conditions, it may be repeated that the public utility is bound initially to the two-fold obligation of good service and reasonable rates. These should be demanded by the public as the consideration for the right to serve the public. The conditions to be outlined are, from the public point of view, the essential guarantors of the ability on the part of the public utility to meet the full public demands.

The first of these conditions is the protection by the public of the bonafide investment of the utility. This can only be done by earnings sufficient to insure the stability of the property, which must include an adequate rate of return to the investors, so as to induce new capital, as required from time to time for the expansion of the business in the public interest. As to the reasonable rate of return, neither the company nor the public can assume to determine the same as against the investor who must furnish the capital. He is

absolutely free to invest his money as he sees fit and will naturally put it where he thinks he can obtain the best return with a degree of security which is satisfactory to him. If public utilities are restricted to rates of return which are unsatisfactory to investors, the inevitable result will be to curtail further investments in utilities, which will mean denial of extended service and impairment of the present service to the public.

There has been a tendency in past years to arbitrarily determine certain fixed percentages as representing the allowable fair rate of return for public utilities; these percentages in some instances being as low as 6% per annum, more often 7, 7½ or 8%, and in some particular cases as high as 9 or 10%. It must be recognized that unless the rate of return allowed to public utilities is comparable to the returns allowed in other lines of business, where the risk is no greater, that the inevitable result must be disastrous to the public. The speaker can say, without hesitation, that if the public interest is to be best served the attitude of regulatory bodies in this respect must be liberalized in future.

It would surely be unreasonable to claim that money invested in national banks in this country is subjected to greater hazard of impairment than money invested in public utilities; yet according to the report of the Comptroller of Currency the net earnings upon the capital and surplus of all the national banks of the United States for 45 years ending June 30, 1914, was 8.64%, while for the period of 7 years ending in 1914 it was the higher figure of 8.98%, or practically 9%, per annum. If investors can place their money in the stocks of national banks subject to the regulation and protection of the United States Government and realize 9% per annum with practical immunity from any impairment of investment through depreciation of physical property or otherwise, why should they be inclined to invest in public utilities excepting at a substantially higher return?

In the American Economics Review of March, 1916, an article appeared by Mr. J. E. Sterrett on the comparative yield on trade and public service investment, in which is given a tabulation of the earnings of a group of 158 properties, not subject to Governmental regulation, as taken from audit reports, covering the years of 1912, 1913 and 1914. The aggregate investment in these properties is reported as $406,829,358 and the annual profits after deducting all costs of expenses of operation and management, including depreciation of plant and equipment, is given as $55,613,659, or 13.67%. It should be remembered that this tabulation covers every property which was audited in this period by such audit company. Some of said companies were far from prosperous and others only moderately so, yet the average profits of all is approximately 14% per annum, and many run as high as 20, 25, 30 and 40% per annum. The fact must not be ignored that public utilities are in competition with such industrial enterprises for the capital which they must have in order to serve the public.

Another very desirable condition is to furnish the public utility with sufficient incentive to unusual efficiency, to insure the highest grade of service at all times. This can only be done effectively through a proper sharing of the advantages of such unusual efficiency between the company and the public. An absolute limitation as to net earnings, irrespective of the efficiency of the service rendered, can never result in the highest degree of efficiency. Human nature does not permit 100% efficiency at all times without some selfish inducements being offered. In other words, there must be a stake if the company is to be expected to play the game at high pressure. Regulation of prices, based solely upon definite rates of return, tend to carelessness as to expenses since the company has nothing particularly to gain by reducing its expenses after the net revenue is equal to the allowable rate of return. The public would be better served in such a case if efficiency were stimulated by a division of results. Maximum efficiency is what the public should seek and the necessary and reasonable compensation for same should be promptly forthcoming.

By way of illustration, two companies may be cited in two cities not far apart, the one company may be charging a maximum rate of 10c per kilowatt hour and without specially good service or any unusual degree of industry or efficiency may be earning a return of 8% per annum on its investment; the other company charging a net rate of 9c per kilowatt hour through unusual efficiency and untiring devotion to business may be able to earn a return of 9% per annum on its investment. In the event of a rate investigation and the application of the theory of the limitation of net earnings to an arbitrary figure of 8%, as has frequently been used in rate cases, the 10c rate of the one company would not be disturbed, because it does not yield in its operations an excessive rate of return, but the lower rate of 9c of the other company would be still further reduced merely because that company, through extraordinary efficiency, is able to earn 9% per annum, although giving the public a superior grade of service, and at a 10% lower rate. This is surely not less advantageous to the public in the long run than it is unfair to the efficient utility company. What ought to be done in fairness to the company charging 9c and earning 9% is to commend it for its efficiency, in which the public is sharing the benefit, and to encourage it to make still further voluntary reductions in rates by permitting it, if it can do so, to earn an even higher rate of return coincidently with its reduction in rates. It is surely much more in the public interest to have a utility company earn a 10% rate of return on a maximum rate of 8c per kilowatt hour than to charge a maximum of 10c per kilowatt hour, even though in so doing it is earning but 8% return. Although this principle has had some slight recognition in certain quarters, the fairness and the importance of such considerations are altogether too little understood and appreciated by the public at large.

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The advantages to all of the application of these primary principles to the improvement of our public relations seem so obvious that it appears strange indeed that there should be any hesitation at all about their recognition and general adoption. Yet we must confess that in many, if not most instances, even now the utilities and the communities which they serve appear to be at arm's length.

The reason must be, either that the utility operators fail to point out convincingly the advantages of a genuine mutuality of relationship, or the public are, due to underlying distrust or otherwise, slow to reach an agreement with their public servants as to the fundamentals of their just and proper relations.

Much of this hesitancy on the part of the public is undoubtedly due to the constant agitation of certain newspapers, organizations and individuals who mostly for selfish and unjust reasons seek to accomplish their own purpose at the expense of the utilities.

These attacks consist of misstatements of facts and misrepresentations of the motives of the utility operators on every possible occasion. They are intended to keep the utilities and the public apart rather than to help them to get together for their mutual welfare.

While such antagonistic agitation is much less evident in some localities than in others, it must be reckoned with in any average situation. To hope to convince and convert the agitators themselves is usually hopeless. They don't want to be convinced because their purpose would not be served by discovering they were in error. They would then have to find some other line of attack to keep them in the limelight; in other words, agitation is not the means to an end, as all proper and honest agitation must be, but with them it is the end to be attained; therefore it will never be voluntarily abandoned.

All the utilities can hope to do is to gradually establish such an understanding with the general public through frank publicity and unfailing courtesy and efficiency of service, that the edge of the poisoned sword shall be turned by the very injustice of the insincere attack. This may of necessity be a slow process, but it ought to be sure in the end.

Let me say with regard to this entire question that I am distinctly an optimist. I do not underestimate, I believe the forces that are working for changed conditions in the industrial and political life of our country. They are many and their methods are devious. Some of them are honest and sincere and some are not. Those that are sincere are not necessarily or even probably right, and those that are insincere are not invariably doing harm. That difficulties lie in the pathway of all of us is certain, but we have no right to call ourselves Americans unless we possess an underlying confidence in the soundness of our institutions and in the honor and fairness of the public when put to the test.

DISCUSSION.

E. G. Cowdery: I endorse every word that Mr. Freeman has said, and I do it from the bottom of my heart. I had thought as Mr. Freeman talked that it might be well to question the reason why we do not seem to have the sympathy and co-operation of the public. It seems that the public, taken as a whole, are naturally antagonistic to the corporation. They are antagonistic to the large corporation. They look upon any corporation that is earning a million dollars a year as an octopus. They do not think anything about the rate of interest, the rate of return, or what the million dollars represents to the capital invested; but simply that there is a company making a profit of a million dollars a year, and they are naturally antagonistic —no one should be allowed to make that much money. It is something like an individual. What is the reason that they have gotten into this attitude?

Of course the attitude of corporations has changed in recent years from what it was years ago. Their methods were secretive. Many of them did make large profits, were glad to cover them up, and for many years they kept the public in ignorance of the amount of money they were making. In the course of time the public became aware that these corporations were making large sums of money and also that they had covered it up for years, and it created a feeling of antagonism.

Now the corporations find themselves in this position: That they must correct that impression with the public; they must teach the public what the conditions are, and they find that difficult. The minute they start out to teach them, they have to begin with certain rudiments, reasons, and so forth, and the public takes the first thing that is mentioned and turns that against them.

They do not give them a chance to continue the argument until they have explained the situation and boiled it down so that they see that one thing fits into the other and are shown the result. Before the public impression is corrected it seems to me that there must be a very wide and extended publicity movement. We have to make the public fully aware of the entire situation, of the profits that are necessary. We have to make them aware that the company must be prosperous, as Mr. Freeman contends. The company can never be served satisfactorily unless the company is sufficiently prosperous to enable it to raise capital each year for its extensions. It has been realized for a long time among corporations, I think, that they must bring about this publicity movement, but they are somewhat slow in doing so, necessarily so, perhaps, to some extent. But that is a system of education that will probably have to be followed up. The appointment of state commissions, and so forth, is perhaps a step in that direction. The acts and doings of these commissions are public, and the public becomes aware, more or less, of the state of affairs with their corporations through the commissions. Unfortunately, these commissions are

appointed from among public men that do not understand the business that they are to regulate. They have to learn that business before they can accomplish very much. They have to make a great many mistakes before they get at the real understanding, and they go through a period of perhaps making things somewhat worse before they reach the point where they are educated to the same extent as the operating men of these corporations and begin to work with them in a helpful way to bring about proper results.

All of the companies today, I believe, are fully aware that they are servants of the public, that they must serve the public to the best of their ability, and they must obtain the good will of the public as rapidly as they can. Progress is probably being made in that direction. I believe that the company I am associated with has made a great deal of progress in the last ten years in rendering good service to the people of Chicago, and I believe that it is appreciated to a very great extent by the public of Chicago. We have a great deal of commendation from the public. We have letters by the score from people that have been so well served at times, that out of the goodness of their hearts they have written us a letter of commendation for some of our acts that were done without any special intent at the time.

The trouble seems to be that we are somewhat in the hands of politicians. Their interest is not, I think, as strong as ours in serving the public. Their interest is creating a situation that is favorable to themselves individually. The public is easily gulled, and if a man stands up and says he is against the corporations and he is going to ruin them, going to do this or that, no matter whether it can be brought about or not, but he is going to do it, he is going to stand for the public, why, they will turn with him and think he is a wonderful man and the politician is usually sharp enough to grasp that idea and make the most of it. We have to deal with these politicians, so that the only thing we can do, probably, is to go on serving the public the best we can and at the same time exercise our ingenuity to educate the politicians, give them to understand finally that they cannot get anywhere along the lines on which they are working. They must learn that they have to get down to business principles, and when they do that, they can give the public the best service as well as help their city to have a prosperous concern that will not only take care of their interests but not make any undue profit.

I cannot say very much more on this subject. It seems to cover the greatest difficulty, I think, we have, and it all boils down to this: That it is a question of education, all along the line, and if we keep going along enough we can hope for some results.

John F. Gilchrist: I want to add a second endorsement under Mr. Cowdery's to all that Mr. Freeman has said. I think if from the beginning of the utility business we had had more Freemans and more Cowderys there probably would not be the feeling that exists in many communities today toward the public utilities. It

seems to me that the great difficulty with which we are contending, we who have the responsibility of serving the public, is in putting our customers and the public in position to see the thing as we see it, and the reverse, the difficulty which people in public utility business have in putting themselves in the position of seeing the thing as the public sees it. I think we have all had the experience as to statements made by representatives of the public with regard to the way in which we should run our businesses, which statements were thought to be ridiculous, that perhaps after years we have reached the conclusion that after all there was more or less truth in their position.

To illustrate my point regarding the difficulty in making people see things in the proper light, I will cite an instance of a case that came to me today. I do not know why it was addressed to me, as it probably should have reached Mr. Lloyd's desk. But somebody who knew my name and who did not write a very good hand wrote in and said that we had been for several years advocating that people wire their houses and he had wired his house, and now that it was wired he found that it would cost him something in the way of deposit to have the company's lines run to his house. He did not say that he was out on the prairie, but I knew that he must be. It is a question which has come up with us and with all utilities. If they were to go out on the outskirts of the city and extend their service indiscriminately to the pioneers in building they would expend a tremendous amount of money, more than any of us realize, until we put it on paper, to get business which for a good many years would be absolutely unprofitable, and such a practice would be a very great injustice to the rest of our consumers, upon whom the burden would fall in the shape of sustained high rates. The commissions have recognized this fact and have studied it and have set certain limits as to what is reasonable. In the case referred to the amount it would cost to extend to the man was just about double what our commission has said was reasonable. Now as I held that letter in my hand I thought, what can I say in a letter that will make this man see the thing as I see it and make him see the fairness of our position. I was satisfied that whatever I said he probably would look on as being unfair. It involved spending a relatively small amount of money, the spending of one hundred and three dollars, to be exact. I suppose we would have received fifteen dollars a year of gross income from this customer, so that it would take six or seven years before we got the cost of our extension back, to say nothing of all the investment we had behind that extension and the cost of generating service for him. Handling his business would have resulted in a decided loss to us. But the point that I wish to bring out is that if I could have sat down with that man, and if he had been a reasonable and intelligent man, as the majority of the people we come in contact with are, I could have convinced him, I am satisfied, of the fairness of our position; but, as it is, where only written communication was

practical, I have no doubt that that man will harbor the feeling that he has been unfairly treated.

You, all of you, have had the experience of carrying on correspondence with men that you do not know. You may not get very close together, whereas, if you knew the man, if you were well acquainted with him, there never would be any differences between you. So that one of the problems we have, and it is a very difficult one, especially in large communities, is to get acquainted with our patrons, convince them of our sincerity of purpose and find out what the special details of their cases are, because we must deal with cases quickly, we must deal with them as types, and yet many times there are circumstances which surround a case which warrant a different consideration from the average cases of that type.

The public utility man is always at a very great disadvantage because the best informed men in commercial life do not understand his business. Take a business like a big commercial house here in Chicago, the big mercantile houses that many men are familiar with. Those people do a business many times the amount of the capital invested in their business each year. Take the State street houses, I do not know what it would run but I was once talking with Mr. Lehmann of the Fair, the oldest of the brothers, and he was talking about the great business of the Commonwealth Edison Company, although he was not very well posted regarding it. At that time we had invested in our business some fifty million dollars. He said to me, "How much business do you do a year?" I said, "Last year we did something over ten millions." "Why," he said, "was that all? We did ten millions here in The Fair." I said, "How much capital have you invested here?" "Well," he said, "possibly two and a half millions." He is a high type of business man and yet he did not appreciate the difference between our business and his business. In his business he turned over his capital four times a year. If he made five per cent on his turn-over, that was twenty per cent on his capital. Some of you gentlemen probably saw the statement of the Armour Company published in the papers a few weeks ago. I think it showed a return of twenty per cent on the capital invested in the business, and yet the meat business is a business of notoriously small per cent of return on the turn-over. Three, or three and one-half per cent, on the turn-over, is considered a very good return. Now you can see how readily a man listening to a discussion of whether a public utility was fairly entitled to an eight per cent return on its business might say, "Why, here is Marshall Field & Company. They make five per cent on their turn-over, and Armour & Company make three and a half per cent on their turn-over. Here is this Edison Company, I understand they generate current for just about fifty per cent of what they sell it to us for, and there is one hundred per cent on the turn-over." When we compare businesses, we were doing ten millions of annual gross on fifty millions of capital and

the Fair was doing ten millions on two and one-half millions of capital, and yet how many people among the public give consideration enough to such peculiarities even though they are intelligent people, to appreciate such a situation, because there are so few businesses—big utilities and the railroads and a few such undertakings that have such conditions.

When the public utility man begins to think about publicity he is between two fires. He is like the gentleman who was about to sell out his store and who expected the prospective buyer to come around at a certain hour. He met a pleasant looking gentleman who came into the store who asked him if he was Mr. Meyer, and he said he was. The visitor said, "You are expecting me?" "Yes, I am expecting you." Then the visitor asked how much he had in stock, and he went into it in great detail and showed him what a fine stock he had and how much it had cost, and when he had finished Mr. Meyer's guest said, "Well, it is some time since I have met such a courteous and fair and frank gentleman as you. I am the new assessor in this part of town and I just came in to see how much stock you had here."

Now, the public utility, on the one hand must raise capital to prosecute its business, and this is one of the difficulties in the business, one that is accountable for such poor service in many of our small cities, inadequacy of plant due to the difficulty in raising capital, and, on the other hand, the utility is confronted by a lot of people who feel that if it shows enough earnings to enable it to raise the capital that it must have, that it is making altogether too much money, and thus it is between the devil and the deep sea. Here is where we must have education again, education of the public.

We must become better acquainted, and as a practical proposition I feel that perhaps we in the public utility business do not take proper advantage of the great opportunity which our large bodies of employes afford us in reaching out and becoming acquainted with the public, inspiring our people with the idea that it is their duty to know about our business, and it is their duty to mingle with people and to use their influence in a way which is fair to the company. We have to deal, as everybody does in business, with the human factor, and sometimes it is quite trying; but I really think we are making progress in that direction.

I feel, as Mr. Cowdery says, there are people who will make capital of the differences which exist between the public and the utilities, and widen the breach for their own personal purposes, but the only thing that we can do is to honestly and earnestly endeavor to conduct the public utility business in a fair and just way, to fully appreciate the rights of the public and to try to bring the personal element into our dealings whenever we can.

William J. Norton: There is one phase of the situation that Mr. Freeman talked about that I think is important, and it is a basis for some optimism at this time. In watching these problems

in the last three or four years it seems to me that the general trend of public feeling is swinging away from its hostility toward the utility companies, and occasionally we can see a little break in the clouds of the public maintaining or beginning to assume a fair attitude.

I recall an incident that happened in Cincinnati under Mr. Freeman which he did not mention, I think. In Cincinnati there was a certain agitator who had jumped into every utility situation in the city. It made no difference to him whether the proposition was fair or unfair, he was opposed to it; and, being a man of some eloquence and power in moving the public, he had obtained a certain following. The renewal of a simple street car franchise came up, and in Ohio the referendum prevails, and this agitator invoked the referendum and managed through his agitation to overthrow this street car franchise, although it was probably as fair and square a franchise as could be offered. He kept up this sort of tactics for a number of years. Finally, at a certain ordinance which the city passed, the same agitator started his tactics again. He went about in the same old way, calling down all sorts of names upon the company, and in the usual way trying to bring the public to defeat this franchise. But he went too far and the public had had too much of it, and when the final vote was counted the ordinance was overwhelmingly sustained. Now, occasionally in the last year or two we find some instances of the public being tired of pure agitation, willing to take a fair side, and I wanted to leave that simple story with you as a matter for optimism and encouragement.

Peter Junkersfeld, M. W. S. E.: I have only two points upon which I might venture to say a few words.

The first is this: That while I recognize fully how easily the public is influenced by the politician, I am sufficiently optimistic to believe that after all the effectiveness of that sort of thing is gradually losing ground. In other words, the politicians have made those promises so many times, over and over, at so many elections, one after another, that a larger and larger proportion of the public are beginning to take less and less stock in it. That is also confirmed by the actual observation and experience of a good many years that, after all, the number of dissatisfied customers is a very small proportion of the total. But, like the one bad apple in the barrel, of course they are more noticeable than the very large proportion of satisfied customers.

The second point that Mr. Freeman dwelt on that I think is particularly pertinent here this evening, where the audience consists principally of engineers, is the duty that every engineer owes not only to himself, but to his state and to his country. A great many of us have obtained our start in life through education at some state university. We have chosen engineering as our profession, as our work. A man is not a real engineer unless he keeps on learning, unless he keeps on getting information to make sure he is right on every point as he goes along. If he does not do that

he is only a would-be engineer. If he takes life easily, takes things for granted, and allows his judgment to be influenced by sentiment rather than by reason, he is hardly entitled to the full dignity of the word engineer, if you will pardon me for saying it. I think, therefore, that we ought especially to take that part of Mr. Freeman's remark to ourselves. Remember that things aren't always what they seem. The real solution and the real facts are not all contained in the headlines. You can see that about you in a great many different ways.

Take, for example, the street car fare in Cleveland that is known very well all over the country and that a great many people are prone to point at,—a three-cent fare in Cleveland. If they have got a three-cent fare in Cleveland why can't we have it here, there and everywhere else? Do not believe the headlines. Find out the rest of the story. Before reaching a conclusion ask yourself this question, as I have found it very profitable to do. Ask yourself this question: "Have I considered every angle?"

Referring again to the three-cent street car fare in Cleveland, that only tells part of the story, because, to begin with, every transfer costs a penny. If you do not happen to have the change, your fare costs you a nickel and not three cents. Every time you ride on an interurban car within the limits of the city of Cleveland you pay five cents. So, when you average it all over, the average amount of money paid by the people of Cleveland per passenger carried on a so-called three-cent fare is greater than that paid in St. Louis, for example, on a five-cent fare. Furthermore, the operating expenses in Cleveland of the railroad company are very different than in many communities. Many items of expense, such as paving between the rails, have to be borne by the street car companies, and, of course, ultimately by the users of street car service. In Cleveland they are not required to pave between the rails.

I think each one of us as an individual should feel it is our bounden duty to keep on getting information and to keep on until we are sure we are altogether right. Before we form a conclusion we ought to be absolutely sure of all the facts.

Lyman E. Cooley, M. W. S. E.: I think we are to be congratulated, the public is to be congratulated, upon the leaders of thought in these matters submitting their cases to the great public opinion where everything, in a civilization like ours, in a government like ours, must finally be arbitrated. That and the courts have been too much ignored in the past is my humble impression. I think that will go a long way even if they do not agree with them. A large part of the public will be content at their having made an endeavor to educate them, whether they understand the question or not. A part of the difficulty seems to have been that of the little girl who had kicked about her piece of bread and butter. She admitted that the bread was good, admitted that the butter was good, but she did not like the way the maid spread it on. A good deal of the trouble has arisen from matters which have been confessed here this evening with

regard to the former course of public utility managers, and that in itself gave an opportunity to the politicians which could not have occurred had they taken the course which they are now taking.

If we go back to the opinion of Charles Devens, back in Grant's administration, I think, for a fundamental definition of the Attorney-General of the United States in regard to the nature of a public utility, it is a public agency only created for a purpose which the public itself has a right to undertake, and in that sense it is accountable to the public and it is an agent of the public. That was recognized fully in the Walla Walla decision in the case of the water works, where the supreme court held that the town could not go into competition in the creation of water works with an agency created for that purpose by the town itself. I think that is a just proposition and the sooner we recognize that and the sooner we hold up the hands of the corporations and seek to learn whether they are doing right or not and insist upon their telling us and informing us, the sooner we will get together and the better understanding we will have.

A part of the trouble has come from the fact that nobody knows what constitutes a proper investment in a public utility. The court in all the cases that have come to it—I now refer to the Supreme Court of the United States—in a number of railroad cases has very deftly and steadily dodged the whole question. We do not know. There is no basis either for the public or for the investor himself to determine what constitutes the proper valuation in a public utility or a proper earning on the part of the utility, considering the risk of the business that is involved.

There is another difficulty which I think we have got to solve sooner or later before we get at a sound basis for reasoning in the premises, and that is some better form of corporation securities. We have now a complex system of stratified securities—stock, first preferred, second preferred; first mortgage bonds, second mortgage bonds, subvention bonds; floating debts, surplus, and so on; and the average man who seeks to reason on the subject and to find out what the actual investment consists of gives up before he starts out. We have got to have some different form of corporation law which will be just both to the investor and to the public to enable us to judge intelligently what our public utilities are doing.

I have always been very much impressed and I have given some study to this question of the form of securities in public utilities. I have done a little appraisement work myself in some classes of utilities, and I have always been impressed with what I understood to be the French idea: Having only one form of security, which draws a moderate rate of interest from the time the investment is started, and that is issued from time to time to cover interest, and also the deficiencies of revenue, until the concern gets to be a going concern. When that point is reached that is the capitalization of the company, and there is no other security allowed except perhaps an emergency security, which may be in the form of limited bonds;

something of that kind, of a limited nature, which can be retired when the revenues or the surplus justifies it.

I think that when we get to the solution of these matters and get them to a proper consideration in a court of last resort, and when we get a proper corporation law, it will not only impart security to the public, but will be something which the managers and operators of the great utilities will themselves welcome, and which the investors will particularly welcome, as it will eventually put the whole utility proposition on the basis, you might say, of an assured or guaranteed income.

Mr. Cowdery: I would like to say a word or two after the talk of Mr. Cooley, because I think it will be a little enlightening, and I am going to risk being a little bit personal, perhaps.

One of our largest newspapers here in Chicago made a statement to our company recently that they actually believed that the gas company ought to have from the city of Chicago what they were asking for, with this possible exception—I think this illustrates somewhat what Mr. Cooley said—they were in doubt as to whether the gas company was entitled to pay interest on the entire amount of its capital stock. Now, to my mind, there is a very clear answer to that question without going into all the intricacies of valuation.

Years back, about 1880, there were two gas companies in Chicago. Both of them had been organized and in operation since eighteen fifty something. Perhaps they had competed a little at the start, but they had practically agreed to divide the territory of the city. One was operating upon the West Side of the city and the other upon the North and South Sides, and they continued that way a great many years. But about 1880 the city council of Chicago, believing that competition in business was the best method of regulation, had authorized an additional company to go into the gas business in Chicago and lay mains and supply the citizens with gas. Now, this was the common council, the agent of the people; that is, the agent of the people because they were elected by the people. The companies did not believe that another company should come in and compete with them, of course. The companies were wise enough to know that this business was not subject to competition. So another company was organized and went into business, and perhaps before that got into operation it was bought up by these other two companies, or maybe there had been some agreement with them, or something of that sort; but, anyway, it created antagonism enough so that the aldermen saw fit to organize another company. So they organized another company, and another company went in and spent its money to still further compete in order to get results for the people. This proceeded in that fashion until they did not wait for a company to get into operation, but they kept on authorizing new franchises, and, of course, that was ruinous to the companies.

That proceeded until about 1897, when there seemed to be a pretty clear understanding, not only with the companies but with

the people, that this business was not subject to competition; and so it was talked around, among themselves, in one way or another, until they all came to the idea that a monopoly should be made of this business and it should serve the city of Chicago. How could it be done? It could only be done by the companies combining together and coming into the hands of one company to serve the city. Those companies could be combined only upon such terms as they would agree upon; and my understanding is, although I was not present in the city at the time, that they were put in according to the market value of the securities of those companies at that particular time. It is natural to suppose that those securities were very much depressed with all this competition, and in an off-hand manner, without looking into it, we may assume that that was a reasonable price for those companies. The stock of those companies amounted at that time to about $25,000,000, according to that market value, and they had a bonded indebtedness upon those companies of some $29,000,000. A consolidation act was passed by the legislature of the state of Illinois, authorizing the organization of the company with $25,000,000 of capital and directing that that company should assume the responsibilities of those companies to the extent of $29,000,000 of bonds. That made $54,000,000 capitalization for that company. Was there water in it? We do not know anything about that, but it is fair to presume, as I said before, that the market value of securities at that time represented a fair value of those properties. The population of the city of Chicago at that particular time, 1897, was 1,600,000 people. Therefore, if you figure it out there was $54,000,000 capitalization to serve 1,600,000 people, or a capitalization of about $34 per head of population. Since that time the city has grown, the company has grown, and many million dollars of capital have been added to this company. Today the population of Chicago is supposed to be about 2,600,000 people, as near as anyone can get at it. The capitalization of the gas company amounts to about $86,000,000. Therefore, the population has grown 1,000,000 people and the capitalization has grown $32,000,00, or $32 per capita. Now, we do know without any question—and the books of the company can prove the story to anybody with very little investigation—that that growth of $32,000,000 represents the actual cash invested during that time. No water has been introduced into that capital during that period and that growth represents $32 per capita against the old capitalization of perhaps $34 per capita or thereabouts. In my opinion it does not indicate very much water in the original capitalization. To my mind that is a complete answer without any great system of valuation, that there isn't any water in the securities of the Peoples Gas Company, and I believe that argument is sufficient to satisfy that newspaper, and if it could be publicly known and appreciated, and the people did not think somebody had lied about it, that they would comprehend and have faith to a more or less extent at least in regard to that capitalization.

When one stops and thinks about it it seems a stupendous

problem to prove whether water is in this capitalization or not, but I believe it is quite simple. True, these companies are muddled sometimes with many different kinds of securities; different kinds of bonds that are put upon it, perhaps, preferred stock, second preferred, common stock, and so forth; but these are all methods that are pursued in order to raise money for these companies to serve the public. Sometimes it is easy to raise money one way and sometimes it is easy to raise money another way; but these various methods are pursued in order to raise capital in the cheapest and best way it can be done at the time, and while it appears muddled when one comes to view it today, to look into it and analyze it, at the same time it is just as fair as any other method that can be pursued.

Harold Almert, M. W. S. E.: I want to say that I think that this meeting is one of the most helpful signs of the times. Necessarily, because of an engineer's occupation he has on his mental camera the strong lenses of narrow area in order to do his work properly, but it is very helpful at times to take those lenses off and put the wide angle lenses on and come out into a meeting of this character in order to view the whole situation, to see relatively the engineer's own importance and the part that he plays in connection with utility work; and for another reason, that his neighbors, knowing that he is an engineer, naturally look to him for an answer to some of these problems which they do not understand.

I was quite in sympathy with Mr. Freeman's expression that he has faith in the American public and that a satisfactory solution will no doubt come about. Just before the opening of the European war I heard two men discuss war in general. One of them said, "What a terrible thing it is to think of the number of people that have been killed because of wars, running up into the millions." The other chap said, "My friend, you are getting on the wrong track. If you will consider from a percentage standpoint the number of people that have been killed by wars the number becomes almost negligible." The other chap said, "Viewed from that standpoint, it is probably true; but if we were to have war in this country today and you and I partook of it and your head and mine were shot off, it becomes very important to us."

So I believe that in the settlement of this question the American public is not going to go very far wrong in the long run; but in the adjustment of it there may be a few heads shot off. There may be a number of public utilities that will be ruined before a complete understanding of the situation comes about. Bad precedents may be established increasing the difficulty of securing capital, so much so, perhaps, that capital will seek other courses because of those precedents.

The engineer in his line of work comes in contact, as a rule, only with the physical elements, those things which can be seen and counted, and the cost of them estimated; and these regulating bodies which have come into existence in the last few years, feeling that

they cannot cope with the situation because they are not technical men, have employed a number of engineers to help them in the solution of the problem. If they happen to get broad gauged engineers that know all the elements to be considered, well and good. But if they happen to get engineers with a limited experience and knowledge of only those things that they can see and count and estimate the cost of, only half the story has been told.

The companies to which the gentlemen have directed your attention, if you were to go out and inventory their properties and estimate the cost in dollars of the physical things you can see, and if they are successful corporations paying dividends, put it down that you can pretty nearly say that for every dollar which you can see in physical there has been an additional dollar spent to put the property where it is. The average engineer knows that there is something more spent than just for those physical elements. He knows that for each dollar in physical property an additional ten, twelve or fifteen cents has been spent for employing him and others like him, in putting that property into being, but the remaining eighty-five cents which is the big bone of contention between the utilities and those that regulate them is the item regarding which he should seek to inform himself. For that reason, I think that it would be helpful to all concerned and that the engineer will be fulfilling his place more fully if we digress for a time and get away from our technical discussions and invite the Freemans and the Cowderys and the Gilchrists, in other words, the operators, financiers and others to help us get some definite information on that other eighty-five cents. Then we can get out and tell our neighbors, the commissions, the aldermen and the others, all of the conditions and all of the elements that must be taken into consideration in order to do full justice to the situation, and then we can bring about the condition which Mr. Freeman speaks of, namely, utility efficiency, with ample capital, to be had without undue effort and without undue cost.

E. W. Allen, M. W. S. E.: These gentlemen have not overstated their case in any way,—they have in fact understated it. I represent the manufacturers, or the people who are endeavoring to change the fashions, so to speak, in this electrical business, and we know from experience that much of it, and particularly generating and substation apparatus, should be changed or superseded every two or three years. Electricity is, of course, the great labor saver, and central stations in these days of high labor cost are going to have their loads increased, but fuel is a very important item in the cost of production and since they cannot increase their rates, what are they going to do to meet the present conditions? Large stations with horizontal turbines of 20,000 to 30,000 kilowatts capacity each are producing the kilowatt hour for 20,000 to 30,000 heat units, but new apparatus is available that will, under favorable conditions, produce the kilowatt hour for from 15,000 to 20,000 heat units, and many relatively new central stations must, therefore, be rebuilt to take advantage of these new economies. If the public utilities cannot get a reasonable return

upon their investment, it is wholly impracticable for them to rebuild their plants, and I think that these facts should be taken into consideration and brought out more plainly, not only in our own discussions, but particularly in discussions with the public. Few of us stop to realize that when we install a large turbo generator that it must earn its first cost in three years or less. We, as manufacturers, maintain a research laboratory and exert every effort to improve the efficiency of our apparatus to such an extent that it is desirable to replace generating apparatus in the time mentioned above.

A. C. King: In connection with the rate of return, as was stated by Mr. Freeman, I think that rates from six per cent upward are generally considered proper. When considering this question the first thought that comes to the minds of the general public is we pay for municipal purposes perhaps four per cent, in some cases even less for money. Why should we allow the utility a rate of fifty to one hundred per cent or more in excess? It seems to me that right on this point the public utilities might well bring into more prominence the fact generally overlooked, that while the municipal plant, as a rule, may obtain money very cheaply, the saving which is made in this respect is often lost and, in fact, greater losses sustained in other directions. There are very few municipal plants where the actual figures are available; and I think if this association would further the matter of looking into the actual conditions and obtaining the actual and true results of municipal plant operation it would be of much assistance in this connection.

I want to say one word with regard to the subject of public opinion in general in connection with utilities. Public opinion is, to a large extent, dependent on the newspapers. Of course, it is realized that the newspapers try to reflect public opinion in order to please their patrons. There is a great deal of good that can be accomplished, I think, by giving the newspapers the proper facts in each case and seeing that they publish them. They, of course, like to publish headlines which attract the eye, and consequently they often publish articles which appeal to the sensational rather than print the actual facts. This has come to my notice a number of times. The individuals on the newspapers are generally fair enough, but they feel in order to curry favor with a certain class of people they have to make the articles sensational, and in doing so it becomes necessary, of course, to rap the utilities.

One of the greatest arguments used against the utility is that it is a monopoly. The great majority of the people have not been educated to the point where they can see that a utility must have a monopoly in order to render the best service. That came to my attention forcibly just a few days ago, where in two cities—small town cities they were—there were two competing telephone utilities. The two companies were conducting negotiations for consolidation. In this particular locality there is not a state utility commission, but the question of rates was taken up with the city officials. These

companies wanted to increase the rate slightly and furnish better service by consolidation, in other words, render a unified service. But there was immediately a very vigorous protest on the part of the citizens, and they began soliciting subscriptions of stock to organize a competing telephone system in case this merger was effected.

R. F. Schuchardt, M. W. S. E.: I recall that just five years ago tonight I had the pleasure of sitting in a corner of the Tivoli Hotel in Panama with our guest of the evening and Dr. Hering of Philadelphia and drawing up resolutions of appreciation, and so forth, to Colonel Goethals and others who had made the week's stay of the American Institute of Electrical Engineers on the Isthmus so very pleasant. Because of Mr. Freeman's splendid command of the English language and his very happy way of stating things, I think we did a pretty good job in those resolutions.

Tonight, in a measure the tables are turned on Mr. Freeman. Practically all the speakers stated resolutions of endorsement of Mr. Freeman's excellent paper, and I want to add my signature to that endorsement.

There is just one thought that occurs to me in connection with the subject that has not yet been touched upon, and that is, what can the employees of the utilities do to most effectively bring about a favorable opinion on the part of the public? We should not scorn the critics, refuse to read their papers, nor call them bone-heads and demagogues; but we should read papers that we know criticise the utilities, get the viewpoint of the writers, or, as the boys say, find out what bug is biting them. It will usually be found to be the bug of ignorance of the real facts. How can we correct this? There is one way that will undoubtedly be found effective and that is to learn all about your utility, particularly the fundamental economics of the business, and then become tremendously enthused over it, or, rather, leave out the "and," because if you find out all about it you will become enthused over it. It is unfortunate that at the very beginning of this business there were so many adventurers at the oar and at the rudder and that in sailing over the seas they encountered so many political adventurers or, rather, pirates, and often they had to fight fire with fire. We are told that such conditions did exist. It is very unfortunate that they did. But we all know that there is a new light in the land now.

Now, then, knowing the real facts of our business and becoming enthusiastic over it will bring results. Enthusiasm is tremendously contagious. I do not mean that the contagion should be spread by constantly talking business, but when you have the opportunity, when you talk to your neighbors or to your fellow club members, let them feel that you are earnestly enthusiastic about the business you are in, and if they have any faith whatever in you, that faith will be reflected by a favorable attitude toward the public utility by those you come in contact with.

Ralph H. Rice, M. W. S. E.: There has been a good deal said

about education. I would like to suggest that we might do a little educating along the line of indicating the advantage to the public of partnership with, or at least co-operation with, the public utility, in some form.

It just occurred to me that we have today finished the tenth year of a large experiment of that kind right here in Chicago with the traction system. Ten years ago this partnership arrangement between the traction companies and the city was started, and while it is perhaps not the best arrangement in all particulars that could be devised now, it has succeeded in doing a great deal of good, I believe, in Chicago. The essence of the arrangement is that every boost for the company is a boost for the citizen. If the citizen assists the company by refraining from improper or unreasonable demands, by just so much is the company enabled to make profits and the company then divides these profits with the city. In just so much as the efficiency is increased, either by the attitude of the company or by the attitude of the citizens, to that extent the profits are increased and both of them receive the benefits. This is the principle that I think might ultimately be developed in some other lines, perhaps not in just the same form, but following the idea, that if you get the citizen to working with you you have the advantage of his helpfulness, at least to the extent of removing his antagonism, and incidentally you may produce a financial profit for him.

Now, just a few figures that occurred to me while some of the other speakers were mentioning figures.

The investment, as you all know, in the surface lines here is approximately $150,000,000, and the ratio of the capital invested to the gross receipts is between four and a half and five. In other words, there is now about $33,000,000 income, gross receipts, yearly from the surface lines. Of this amount the city of Chicago is now receiving approximately ten per cent. In other words, the city of Chicago is now receiving approximately $3,000,000 a year. This will, of course, increase as the years go on. Based on Mr. Cowdery's figures of 2,600,000 population and the capitalization of $150,000,000, it makes about $57.00 invested capital per inhabitant. These are interesting figures as showing the magnitude of the business involved, all of it coming in by nickels, and I would like to suggest that we might help to educate the public in such a manner, and take them into partnership in our utilities in some form, that they would become active co-workers with the utilities and would profit by it in service and ultimately financially. I believe these should not be, and there is not now any fundamental and inherent antagonism between the public and the modernized public utility corporation.

E. N. Lake, M. W. S. E.: There is a note of optimism that has not been introduced so far, and that is this: Don't you think that the women, with their constant experience in dealing with obsolescence in the consideration of the spring, summer, fall and winter styles of each succeeding year, will be of great assistance when they

take a more active interest in public affairs in dealing with these questions of obsolescence in public utility equipment?

There is one additional point which I would like to bring out: I have been impressed with the extreme meagreness of the points of contact between the public utility executive and the public which he serves; with how few the opportunities are for him to know by actual personal contact, or by actual personal report, just what the public attitude is towards his organization.

Take, for example, the steam railroad president. What are the points of contact with the public? The ticket window, the conductor's punch, the freight receipt or bill of lading, the lawyer who brings in a personal injury case, the newspaper, the Congressional record and the various House records of the legislatures in the states in which his lines operate. These are not really good points of contact, are they? These are not reliable or representative sources from which to judge the public mind.

Other utilities have similarly meagre points of contact with their customers, so when a public utility executive speaks of the public and the public attitude towards his business, he is apt to be governed by the latest newspaper criticism or the most recent council or legislative action which has been directed at his enterprise. These criticisms and actions are not necessarily representative of the public mind. They may be, and usually are "misrepresentative."

Closer contact with the people served, together with additional care in maintaining the service at a high standard, will undoubtedly reveal that the majority of the customers are really friendly to the utilities which serve them.

It is not quite fair to arraign the public in general for antagonism when the sources of information as to its real attitude are so limited.

Chairman Wray: I would just like to make one word of comment in respect to Mr. Rice's talk, and that is to call attention to the fact that the form of partnership existing between the surface lines and the city of Chicago necessarily results in a species of special, though indirect, taxation. It has its advantages, but to my way of thinking there are some disadvantages. First, that it is a special mode of taxation and taxation on a class, and, second, that perhaps there is an incentive to the impairment of the service shared in by the company and the municipality.

Now, in respect to Mr. Lake's remarks, it strikes me that the telephone company has more points of contact with the public than any other utility, and I would like to call on Mr. Allen.

A. P. Allen: I am going to explain that I have been with the telephone company twenty-seven years (although I graduated as an engineer before I started with it), and I think that anybody who went through twenty-seven years of Bell Telephone experience has received a demonstration—because it has certainly been a turmoil from start to finish—in relation to the public's attitude toward utilities. When the telephone started the public would not accept it as a

utility; they thought it was only a toy, and it was hard to get anybody to take it. Then when it began to get useful the public thought that the only way to treat the telephone company was to subject it to competition, and I have got literature in my files which reads exactly like recent decisions of public utility commissions under the law. We told exactly, fifteen or twenty years ago, what would happen if they allowed competition to get into the telephone business; because while you can rather easily conceive of competition in gas, with perhaps a slight increase in cost, in a city as big as Chicago; and you can even conceive (if they had proper arrangements) of having fairly good surface car service, with three or four companies (if they co-operated at all), yet it is absolutely impossible to conceive of good telephone service with two competing companies, because they have to *serve the same area,* which the others do not have to do. So, it is very gratifying, in a way, to be able to pull out of your files letters that you wrote fifteen years ago predicting what would happen if they allowed it to come; and if the public had been wise enough they could have found the right solution then as well as in the last five years. But the public is very slow to learn, and that is the chief source of the trouble that they have with their utilities. If they would profit, as I said, by the education which the utilities offer to them, and the utility engineers offer to them, and which they could prove the truth of if they wanted to, they would get along very much faster. So I think that all these troubles that we have now are coming out all right, but it is going to be rather slow.

I look upon this matter of exact return on the investment as a mere detail that will settle itself. It will not settle itself, though, until the public takes the right attitude as to whether they want the utilities prosperous or not. That is a fundamental question. If they do they will allow a proper return, and the exact amount making up a "proper return" will have to settle itself. Nobody here can tell what a proper return on a utility, or anything else, will be fifteen years from now. But I am sure it will come out all right and to the satisfaction of everybody if they get the fundamental right; that a utility, like any other person they deal with, should be prosperous. You do not want to deal with a butcher that you feel is on the ragged edge of bankruptcy and that you feel is tempted to put something over on you every time he sells you anything. You want him to be prosperous. And you want your public utilities to be prosperous; and they will be when you admit that you will allow them a proper return on the investment.

Another thing: I really believe adequacy of service is the principal thing and the cost to the public is only incidental. I do not believe there is a utility in the city where a reduction in rate is important at all; and yet it is true that the newspapers and the public agitators can get up more of a hurrah meeting over the price of gas or the price of the street car fare than anything else. The charge for public utility service has never been anywhere near equal to its

value, but the public does not realize it because they have not had to do without it. What would happen to them if the service were inadequate? A difficult problem with the telephone company is due to the fact that we cannot possibly at a moment's notice provide additional facilities. It takes years to get them. A year and a half ago when everything slumped we determined we might gain twenty or twenty-five thousand additional subscribers in Chicago. We have gained fifty thousand. The business equals in annual growth all that Chicago had a few years ago. We had to provide for this. You cannot handle telephone service by delaying it. It must be instantaneous, or the service is bad. I sometimes wish we had a legitimate excuse for shutting down service for a while. Every time there is a bad accident to the street car service for which the company is not responsible—a truck breaking down in front of the car, for instance—they ought to use it in publicity. Those are the kind of things that finally get under the skin of the public and let them understand what you are talking about. If you talk about a return of seven or eight per cent they do not know anything about it and it looks high to them; but if you can convince them as to the need for *adequacy* of service, and that you must have the utilities prosperous in order to get adequate service, I think it will finally make some impression on them.

INFORMATION CONCERNING APPOINTMENTS IN THE ENGINEER OFFICERS' RESERVE CORPS, U. S. ARMY

Copy of Form No. 163, W. D. Engineers

(Extract from General Orders No. 32)

1. The Officers' Reserve Corps is authorized by sections 37-40, 49, and 51-53 of the National Defense Act approved June 3, 1916.

2. The regulations prescribed by the President to carry the same into effect are published in General Orders, No. 32, War Department, July 28, 1916, which also quotes in full the above-mentioned sections of the National Defense Act.

3. The following extracts from the above general order give the principal requirements of the regulations that apply to the Engineer Officers' Reserve Corps. A copy of the complete regulations will be furnished on request, which should be addressed to the Chief of Engineers, United States Army, Washington, D. C.

4. Applicants commissioned in the Officers' Reserve Corps will rank in the various sections according to grades and to length of service in their grades. Commissions will be issued for periods of five years. No age limits apply to the Engineer Officers' Reserve Corps.

5. Except as otherwise herein provided, a member of the Officers' Reserve Corps shall not be subject to call for service in time of peace, and whenever called upon for service shall not, without his consent, be called in a lower grade than that held by him in said Reserve Corps. In time of actual or threatened hostilities the President may order members of the Officers' Reserve Corps, subject to physical examination, to temporary duty with the Regular Army, or as officers in volunteer or other organizations that may be authorized by law, or as officers at recruit redezvous and depots or on other duty. They may be promoted to vacancies in volunteer organizations or to temporary vacancies in the Regular Army, as prescribed in the act. While Reserve officers are on such service they shall be entitled to the pay and allowances of the corresponding grades in the Regular Army.

6. Department commanders and the Chief of Engineers, when authorized by the Secretary of War, may order Reserve officers

March, 1917

of their departments or corps to duty with troops in the field or at field exercises or for instruction for periods not to exceed 15 days in any one calendar year. While so serving such officers shall receive the pay and allowances of their respective grades in the Regular Army. These periods will not be extended except with the consent of the reserve officers concerned.

7. Enlisted men of the Regular Army and of the National Guard, both active and retired, if citizens of the United States, are eligible for examination for commissions in the Engineer Officers' Reserve Corps. No applicant will be examined who is an officer of the Regular Army on the active list or of the National Guard or who is not a citizen of the United States.

8. The examining board will ordinarily be composed of one officer of the Corps of Engineers, one member of the Engineer Officers' Reserve Corps, and one officer of the Medical Corps or the Medical Officers' Reserve Corps.

9. The mental examination of no applicant will be undertaken who, in the judgment of the board, is not physically qualified to discharge in active service all the duties of an officer of the grade in which the applicant seeks a commission in the Officers' Reserve Corps; nor of any one who has any mental infirmity or deformity of body, or whose moral fitness has not been duly established.

10. No person shall be examined for appointment in the Engineer Officers' Reserve Corps unless he has a letter from the Chief of Engineers authorizing his examination. Such a letter to an applicant will be the acknowledgment of the receipt of his application.

11. If an applicant has served in the Regular Army of the United States, or in any of the Volunteer forces of the United States, or in the Organized Militia of any State or Territory, or the District of Columbia, he shall submit his discharge papers for each term of service; if still in service of any of the organizations named, he shall submit recommendations of his immediate and higher commanders.

12. If an applicant has attended or pursued a regular course of instruction in any military school or college of the United States, or has graduated from any educational institution to which an officer of the Army or Navy has been detailed as superintendent or professor pursuant to law, he shall, if a graduate, be required to present a diploma or certificate of graduation from such military school, college, or educational institution, or, if not a graduate, a certificate showing

the amount and character of training, theoretical or practical, satisfactorily completed thereat.

13. Every applicant will be subjected to a rigid physical examination which shall include the ordinary analysis of the urine, and if there be found to exist any cause of disqualification which might in the future impair his efficiency as an officer, he will be rejected. Defects of vision resulting from errors of refraction which are not excessive, and which may be entirely corrected by glasses, do not disqualify unless they are due to or accompanied by organic disease.

14. Candidates for appointment in the Engineer Officers' Reserve Corps will be examined either (*a*) for duty with combatant Engineer troops or other duties in the service of the front, or (*b*) for special service on the lines of communications or other points in rear, including Engineer work in connection with seacoast defenses, as hereinafter indicated. Officers appointed under (*b*) will not ordinarily be assigned to combatant duties but will be subject to such assignment whenever needed. The examinations shall be especially directed to ascertaining the practical capacity of the applicant, and the record of previous service and training of the applicant shall be considered as a part of the examination.

Military experience or training in the Regular Army, Volunteers, or National Guard, or at training camps or educational institutions, will be noted and reported by the board and considered in making the recommendations.

A. QUALIFICATIONS FOR RESERVE OFFICERS, SERVICE OF THE FRONT.

1. For first and second lieutenants.

(*a*) The applicant must be an engineer in the active practice of his profession or some business immediately connected with, or concerned in, engineering matters.

(*b*) He must either hold or have qualified for the grade of junior engineer, civil, electrical, or mechanical or higher grade in the civil service, or he must be a graduate from an approved engineering college, or have been in the active practice of engineering for at least two years.

2. For captains.

(*a*) The applicant must be an engineer in the active practice of his profession or some business immediately connected with, or concerned in, engineering matters.

(*b*) He must either hold or be eligible for the grade of assistant engineer in the Engineer Department at large, or a corresponding engineer grade in the civil service in another department of the Government service, or have held a commission in the Corps of Engineers of the Regular Army, or shall be a professional engineer not less than 28 years of age, who shall have been in the active practice of his profession for at least eight years and have had responsible charge of work as principal or assistant for at least two years. The graduation from a school of engineering of recognized reputation shall be considered as equivalent to two years' active practice.

(*c*) Knowledge of the principles of military organization and operations, as illustrated in Infantry Drill Regulations, Parts I (to include School of the Company) and II, and Field Service Regulations, Part I and Part II (Articles I, II, IV, VI) ; and of the general principles of field fortifications, as illustrated in the Engineer Field Manual, Chapter V.

3. For majors.

(*a*) The applicant must be an engineer in the active practice of his profession or some business immediately connected with, or concerned in, engineering matters.

(*b*) He must hold the grade of assistant engineer in the Engineering Department at large, or corresponding engineer grade in the civil service in another department, or have held a commission in the Corps of Engineers of the Regular Army not more than two grades below that for which he desires to be listed, or shall be a professional engineer not less than 35 years of age, and shall have been in the active practice of his profession for 15 years, who shall have had responsible charge of work for at least five years, and shall be qualified to design as well as to direct engineering work. Graduation from a school of engineering of recognized reputation shall be considered as equivalent to two years of active practice.

(*c*) In addition to fulfilling the qualifications given in paragraph 3 (*a*) and (*b*), the candidate will be required to pass an examination on the following subjects:

Drill Regulations, Parts I (School of the Company and Battalion only), II, III, Infantry Drill Regulations.

Field Service Regulations, entire text.

Duties of Engineer officers and troops in war, as illustrated in

the Engineer Field Manual and Bulletin No. 4, Volume I, of the Office of the Chief of Staff.

Co-operation between the various arms of the service, as illustrated in "Technique of Modern Tactics" (Bond and McDonough), Chapters VIII, IX, XI, and XII.

All examinations will be oral.

B. QUALIFICATIONS FOR RESERVE OFFICERS, SPECIAL SERVICES.

Candidates desiring appointment in special services must be qualified for at least one of the duties assigned to the Corps of Engineers by the following extracts from Army Regulations:

"1493. The duties of the Corps of Engineers comprise reconnoitering and surveying for military purposes, including the laying out of camps; selection of sites and formation of plans and estimates for military defenses; construction and repair of fortifications and their accessories ; * * * the installation of electric power plants and electric power cable connected with seacoast batteries; * * * construction and repair of military roads, railroads, and bridges; military demolitions; * * * In time of war within the theater of operations it has charge of the location, design, and construction of wharves, piers, landings, storehouses, hospitals, and other structures of general interest, and of the construction, maintenance and repair of roads, ferries, bridges, and incidental structures, and of the construction, maintenance, and operation of railroads under military control, including the construction and operation of armored trains."

No oral or professional examinations will be required, but recommendations of boards will be required in lieu of such examinations. Candidates will submit evidence of their actual employment in corresponding or higher positions in civil life and references to persons under whom they have been or are employed.

Reserve officers from the following civilian occupations will be required for the special services of the Corps of Engineers:

Bridge engineers.

Constructing engineers (earth and concrete).

Constructing engineers (wharves, piers and buildings).

Electrical engineers (for small plants and power lines).

Highway engineers.

Mining engineers (skilled in tunneling and use of explosives).

Railroad engineers (construction and maintenance).

Railroad operating officials.

Sanitary engineers.

Topographical engineers.

Application blanks may be obtained from the Secretary of the Western Society of Engineers, 1735 Monadnock Block, Chicago, Ill.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings

Meeting No. 963, March 5, 1917.

The meeting was called to order at 8:00 P. M., with Mr. W. W. DeBerard in the chair, with about sixty members and guests present. The Chairman announced the death, on March 4th, of Walter Katte of New York, who had recently been elected an Honorary Member of the Society. He then introduced the speaker of the evening, Mr. Raymond W. Dull, M. W. S. E., who gave an illustrated talk on the "Preparation of Rock Products," describing most of the larger gravel handling and washing plants in the United States. Discussion followed from Messrs. S. G. Artingstall, Jr., J. W. Lowell, Jr., J. A. Sauerman, John F. Hayford, William Artingstall, B. E. Ahlskog, and H. S. Shimizu.

The meeting adjourned at 10:00 P. M.

Meeting No. 964, March 12, 1917.

This was a meeting of the Bridge and Structural Section, and was called to order about 8:00 P. M. by Chairman Stineman of that Section, with about 125 members and guests in attendance.

The Secretary announced that the following had been elected to the grades indicated:

No. 66—1916, Frank J. Eckenfels, Moundsville, W. Va.....Associate Member
No. 3—1917, George E. Seibert, Bridgeport, Ohio........Associate Member
No. 9—1917, George R. Volz, Arlington Heights, Ill......Student Member
No. 10—1917, Rector Egeland, Chicago ....Junior Member
No. 11—1917, Emmet R. Marx, Milwaukee, Wis. (Transfer from Student) ....Junior Member
No. 12, Wallace A. Sawdon, Chicago.....................Associate Member

and that the following had made application for membership in the Society:

No. 13—Laurence J. McHugh, transfer from Student.
No. 14—Joseph K. Hilton, Sac City, Iowa.
No. 15—Emil J. Schmidt, Chicago.
No. 18—William L. McNamara, Chicago.
No. 19—Walter S. Lacher, Chicago, transfer from Associate.
No. 20—Walter Buehler, Chicago.
No. 21—Elmer W. Hildebrand, Chicago.

The speaker of the evening, Mr. O. F. Dalstrom, M. W. S. E., was then introduced, who gave a description of the C. & N. W. Ry. bridge over the North Branch of the Chicago River, at Deering. This was illustrated by numerous lantern slides.

Supplementing this, Mr. C. H. Norwood, M. W. S. E., who had charge of the mechanical equipment of this bridge, gave a short paper describing the machinery used to operate the bridge.

Discussion followed from Messrs. C. H. Norwood, O. E. Strehlow, J. E. Cahill, J. W. Lowell, Jr., D. N. Becker, J. C. Blaylock, D. P. Riordan, E. N. Layfield, T. W. Clayton, R. M. Phinney, and John B. Johnson.

The meeting adjourned about 10:30 P. M.

Meeting No. 965, March 26, 1917.

The meeting was a joint meeting of the Chicago Section, A. I. E. E., and the Electrical Section, W. S. E. The meeting was called to order about 8:00 P. M., by E. W. Allen, Chairman of the Electrical Section, W. S. E., with about 200 members and guests present. Mr. Allen called Mr. Ralph H. Rice to the chair, who then introduced the speaker of the evening, Mr. Bion J. Arnold, M. W. S. E., who gave a talk on "The Financial Plan of the Report of the Chicago Traction and Subway Commission." Mr. Arnold used lantern slides in describing some of the points of his talk.

Discussion followed from Messrs. F. F. Fowle, Garrett T. Seely, P. Junkersfeld, J. R. Bibbins, J. W. Mabbs, and E. N. Lake.

The meeting adjourned about 11:00 P. M.

E. N. Layfield,
Secretary.

BOOK REVIEWS

THE BOOKS REVIEWED ARE TO BE FOUND IN THE LIBRARY OF THE SOCIETY.

WATERWORKS HANDBOOK. Compiled by Alfred Douglas Flinn, Deputy Chief Engineer, Board of Water Supply, New York; Robert Spurr Weston, Professor of Public Health Engineering, Massachusetts Institute of Technology, and Clinton Lathrop Bogert, Assistant Engineer, Board of Water Supply, New York. McGraw-Hill Book Co., New York, 1916. 825 pages. 9¼ in. by 6¼ in. Flexible cover. Price, $6.00.

The purpose of this book, as stated in the preface, is to give a usable compilation of information, old and new, for the waterworks engineer and superintendent, the designer, constructor, operator and inspector.

The contents are as follows:

Part I. Sources of Water Supply.

Chapter I. Rainfall, or Precipitation.
Chapter II. Evaporation.
Chapter III. Run-off and Steam-flow.
Chapter IV. Ground Water.

Part II. Collection of Water.

Chapter V. Intakes.
Chapter VI. Watershed Development by Reservoirs.
Chapter VII. Masonry Dams.
Chapter VIII. Rock-fill Dams.
Chapter IX. Earth Dams.
Chapter X. Wells.
Chapter XI. Infiltration Galleries.
Chapter XII. Notes on Some Equipment for Treating Water.

Part III. Transportation and Delivery of Water.

Chapter XIII. Open Channels.
Chapter XIV. Aqueducts.
Chapter XV. Plate Metal Pipes.
Chapter XVI. Wooden Pipes.
Chapter XVII. Reinforced Concrete Pipes.

Part IV. Distribution of Water.

Chapted XVIII. Cast-iron Pipe and Specials.
Chapter XIX. Distribution Systems.
Chapter XX. Valves, Sluice Gates, Hydrants.
Chapter XXI. Service Meters.
Chapter XXII. Pumps, Pumping Stations and Equipment.
Chapter XXIII. Distribution Reservoirs, Standpipes and Tanks.
Chapter XXIV. Water Consumption.
Chapter XXV. Hydraulic Computations.
Chapter XXVI Masonry and Puddle.
Chapter XXVII. Non-ferrous Metals (also Corrosion of Iron and Steel).
Chapter XXVIII. Capacity and Conversion Tables.
Chapter XXIX. Miscellany.

Public Utility Rates. A Discussion of the Principles and Practice Underlying Charges for Water, Gas, Electricity, Communication and Transportation Services. By Harry Barker, Associate Editor, *Engineering News*. McGraw-Hill Book Co., New York, 1917. 380 pages, 6 in. by 9 in. Price, $4.00.

The author has undertaken to present a comprehensive discussion of (1) such corporation and municipal activities as affect service and rates, (2) the trend of public opinion, and court and commission decisions, and (3) the most important engineering and economic problems involved.

He states that it has seemed to him that many men who were interested in these problems have not had the time or opportunity to study the conflicting and reiterative ideas of the scattered documents, pamphlets and papers which very largely form the literature of the subject. In his experience as an engineering editor, and in following the discussion of public-service questions, at engineering conventions and elsewhere, he has kept notes which have resulted in this book. He has endeavored to make a broad survey of the rate problem free from the mass of obscuring detail which necessarily marks individual cases, with the hope that it would be useful to lawyers and legislators, editorial writers and the general public, as well as to engineers. The arrangement is good and the book well printed and indexed.

The contents are as follows:

Journal of the Western Society of Engineers

Vol. XXII APRIL, 1917 No. 4

GRAPHICAL CALCULUS

With Special Reference to Shear, Moment and Deflection Diagrams

By Charles A. Ellis*

Presented January 29, 1917

The instructor was quizzing a senior engineering student on the topic of maximum bending moment in a beam ten feet long simply supported, and uniformly loaded with 400 pounds per foot. (Fig. 1.) The young man had written the correct expression $M=2000x-200x^2$ for the moment at any distance x from one support. He admitted that x was a variable but was quite convinced that M must represent a constant quantity, giving as his reason that M was "one of the first letters of the alphabet."

This was an interesting discovery. Further quizzing was none the less productive. When the student's attention was directed to the idea expressed in the word "Orpheum," he immediately thought of vaudeville; "Bradley's" at once suggested an ice cream soda. The instructor then asked this question: "What idea does the word calculus present?" After some hesitation the young man replied, "Eight hours credit." Investigation revealed that this student had received respectable grades in Differential and Integral Calculus.

Nor is this a single isolated case, as the following illustration will prove. A written quiz, given to seventy junior engineering students, who had in a previous semester completed their courses in mathematics and mechanics, contained this problem: AB (Fig. 2) represents a plane area. Find by any method known to you, the value of the integral expression $\int_B^A xy\,dy$. Over ninety per cent of the students attempted the formal, symbolic process of integration. Less than three per cent of the class appreciated the fact that the integral expression represented the statical moment of the plane area about the line OX, and proceeded with arithmetic multiplication accordingly.

These and many other similar experiences with advanced engineering students force the issue that few subjects deserve and

*Professor of Structural Engineering, University of Illinois.

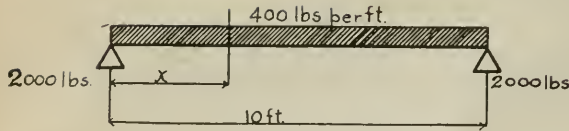


Fig. 1

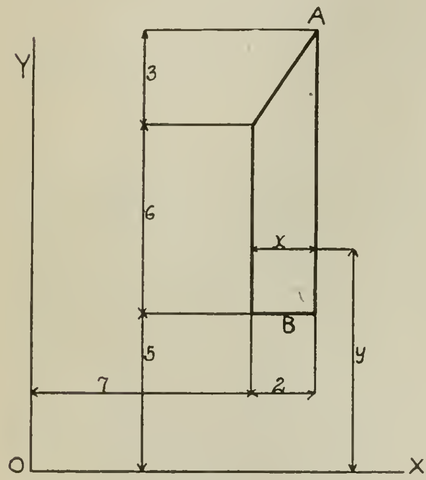


Fig. 2

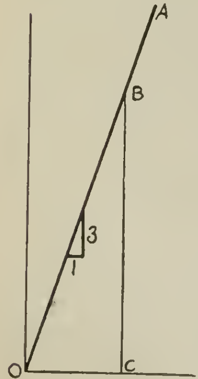


Fig. 3

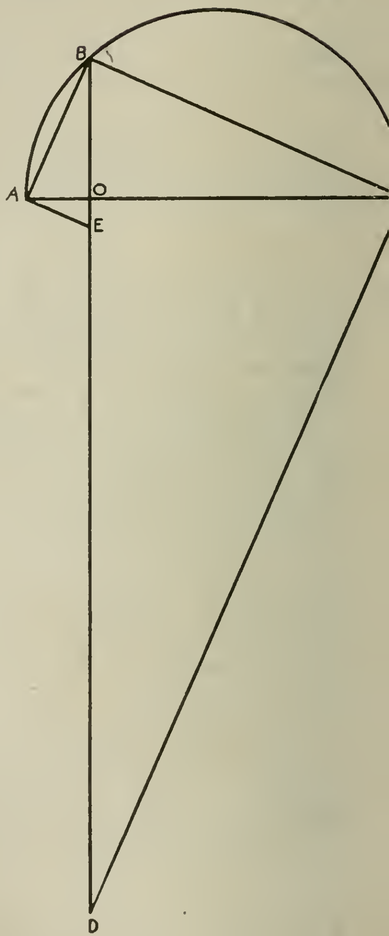


Fig. 4

demand better attention than the very subtle problem of teaching pure and applied mathematics to the average engineering student of today.

Many teachers of the professional engineering subjects believe that too much time is spent by the freshman and sophomore college student in the mathematical juggling of algebraic transformations into pseudo-useful formulas. Now, there is a time and place for rational formulas, but certainly not at the beginning of an engineering course. Their use in any classroom should be kept in very narrow limits, for the simple reason that they are the devil's advocate, doing more harm than good by obscuring physical relations which should be visualized to the highest degree.

Gauss, one of the greatest physical mathematicians of the nineteenth century, remarked that many of the most celebrated mathematicians, Euler very often, Lagrange sometimes, had trusted too much to the symbolic calculation of their problems, and would not have been able to give an account of the meaning of each successive step in their investigation. Gauss said that he himself, on the other hand, could assert that at every step which he took he always had the aim and purpose of his operations before his eyes without ever turning aside from the way. The same, he remarks, might be said of Newton.

The standard text-books on theory of reinforced concrete are probably the best examples of formulas running riot. The procedure for the investigation or design of a beam usually follows this order. Algebraic symbols are given to the various data; the solution appears in the disguise of a group of a half dozen or more formulas, and ever thereafter the numerical values are assigned to the algebraic symbols, the crank is turned and out pops the answer. The whole essence of the ultimate good resulting from mental discipline is lost, the fundamentals are obscured by the algebraic "substitution in the formula"; and what might have been an interesting and instructive problem falls to the level of a high school problem in algebra.

The formula method necessarily presents mathematical principles in generalities first, and particulars last. A history of any science will show that its development has been induced in the reverse order. A science should be presented to the student in the order of sequence most natural for the grasp of the human intellect, which can be no other than that by which all science is developed, namely, by progress from the particular to the general. Any other order is as confusing to the mind of the student as an attempt to interpret the plot of a movie drama, when the film is made to run backwards.

We arrive at conclusions through the analysis of phenomena presented to the mind by the senses. Some phenomena are so simple or potent that their appeal to any one of the five senses is sufficient. It is unnecessary to see Limburger cheese in order to be aware of its presence. We recognize an apple when we see one, but are

thrice assured of its existence after feeling and tasting. There are neckties so loud that they may be both seen and heard.

But mathematical expression appeals to the vision alone. It is, therefore, a distinct advantage to have as many viewpoints as possible. This brings us to a consideration of the two methods of presenting mathematical truths, the algebraic and the graphic. The question—Which method is better?—is one which functions with the individual problem, but it is quite safe to assert that both are better than either taken alone.

No engineer, whose time is valuable, would compute the stresses in a roof truss by an algebraic method, nor would he find graphically the reactions of a simple beam supporting vertical load. However, if each of the two problems is solved by both methods, the fundamentals are more clearly set before the beginner.

It is quite natural that the structural engineer should think of graphics only as a method of solution for roof-truss stresses. Consequently it may be interesting to consider briefly a somewhat wider range of problems which are subject to graphical solution.

Arithmetical Problems

Two quantities can be added graphically if laid off to some scale in the same direction, beginning the second at the end of the first. Their sum is obtained by scaling the resulting line. Subtraction is accomplished by beginning both lines at the same point. Any multiplication table is easily constructed. Fig. 3 is the table of three. The bevel or slope of the line OA is three units vertical to one horizontal. Suppose that the product of four and three is desired. Lay off OC equal to four. The vertical BC will scale the product twelve. Division is achieved in a similar manner.

Problems in involution and evolution are illustrated in Fig. 4. The square root of 7 is desired. Lay off in a straight line OC equal 7 and OA equal 1. Draw a semicircle on the diameter AC, and erect a perpendicular at O meeting the circumference at B.

Then $OB = \sqrt{7}$

For in the similar triangles AOB and BOC,

$$\frac{OA}{OB} = \frac{OB}{OC}$$

$$\text{or } \frac{1}{OB} = \frac{OB}{7}$$

Hence $OB^2 = 7$
or $OB = \sqrt{7}$

Again, suppose that the square of 16.3 is required. Lay off OB equal 16.3 and OA equal 1, making the angle AOB equal a right

angle. Draw BC perpendicular to AB meeting AO produced at C, then

$$OC=16.3^2$$

Similarly $OD=16.3^3$

$$\text{and } OE=\frac{1}{16.3}$$

Graphical methods will compare favorably with slide rule computations in matters of precision.

If the six arithmetical operations of addition, subtraction, multiplication, division, involution and evolution, can be performed graphically, it logically follows that any problem which can be solved by arithmetic processes can also be solved by graphic methods.

Algebraic Problems

Let OX and OY (Fig. 5) represent two fence lines, OX running east and west, and OY running north and south. The location of any point in the field is known if its perpendicular distances from

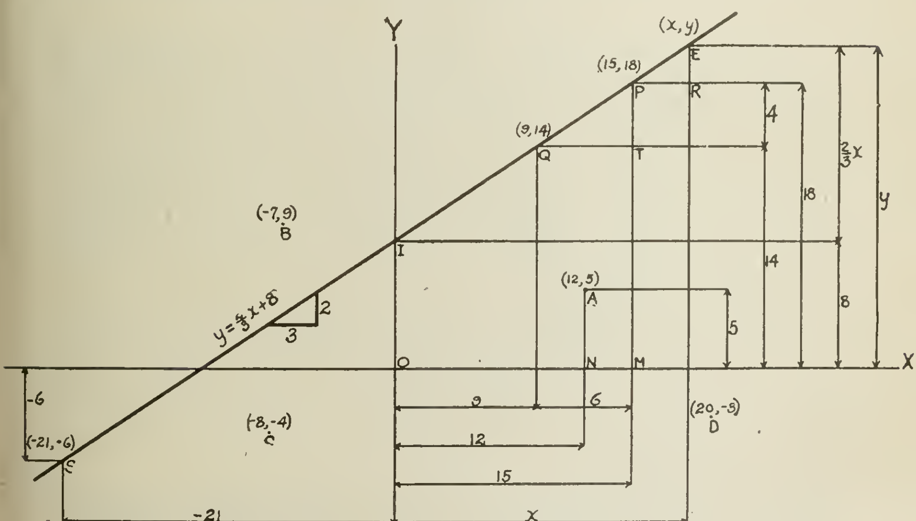


Fig. 5

the two lines are given. Thus the man at A is definitely located if we are told that he is twelve rods east of OY and five rods north of OX. The lines ON and NA are called the co-ordinates of the point A with refernce to OX and OY; ON is the abscissa and NA the ordinate. Mathematically speaking, A is the point for which the abscissa is 12 rods and the ordinate 5 rods or the point (12, 5).

In order to distinguish between north and south or east and

west, we designate distances measured north or east as positive and distances measured south or west as negative. Thus B is the point (—7, 9); C is the point (—8, —4), and D is the point (20, —3).

Now suppose we are told that a man's distance from OX equals $\frac{2}{3}$ (his distance from OY) rods plus 8 rods. The point P satisfies this condition, for if we take the distance $OM=15$ rods, then PM is $[(\frac{2}{3}\times 15)+8]$ rods$=18$ rods. But this condition alone does not definitely locate the man, for there are many other points in the field for which this statement is equally true. Among others, the point Q, having for its abscissa 9 rods and for its ordinate $[(\frac{2}{3}\times 9)+8]$ rods$=14$ rods, also satisfies the condition. Or the man might be at S where the abscissa is —21 rods and the ordinate $[\frac{2}{3}(-21)+8]$ rods $= -6$ rods. Any point which satisfies the condition will be found to lie on a certain straight line in the field. This line may represent a path along which the man is walking and at all points in his journey his distance from $OX=\frac{2}{3}$ (his distance from OY) rods plus 8 rods.

If at any point E in his journey we let x equal the man's distance from OY and y his distance from OX, then we have

$$y=\tfrac{2}{3}x+8.$$

Now just as the point A represents (12, 5), so the line SP represents graphically what the equation $y=\frac{2}{3}x+8$ expresses algebraically. The equation does not locate the man's position in the field. It simply confines his movements to the straight path represented by the line SP. Any value whatever may be assigned to x and a corresponding value of y may be obtained from the equation; and these values will represent respectively the abscissa and the ordinate of some point on the line. The line SP then, is the graph of the equation, $y=\frac{2}{3}x+8$.

If any two points in a line are chosen and the length of the line between them is made to form the hypothenuse of a right triangle, the other two sides being vertical and horizontal, respectively, the ratio $\dfrac{\text{vertical side}}{\text{horizontal side}}$ is called the slope of the line. When an equation is written in the form $y=mx+b$, m is the slope of the line, and b is the ordinate of the point on the y axis through which the line passes. Thus in the equation $y=\frac{2}{3}x+8$ we note that the slope of the lines SP is $\frac{2}{3}$ and that the intercept OI on the y axis is 8. A line slopes northeast and southwest if m is positive; northwest and southeast when negative. Hence the equation of a line may be written at once if its slope and intercept are known.

The equation of a line may also be written if two points on the line are known. Suppose the equation of the line which passes through the two points (9, 14) and (15, 18) is desired. Let E represent any other point on the line, coordinates of which are x and y.

Then in the similar triangles ERP and PTQ,

$$\frac{ER}{PR}=\frac{PT}{QT}$$

$$\text{or }\frac{y-18}{x-15}=\frac{18-14}{15-9}=\frac{4}{6}=\frac{2}{3}$$

which, when simplified, gives

$$y=\tfrac{2}{3}x+8$$

Suppose that the two known points are S and Q.

$$\text{Then }\frac{y+6}{x+21}=\tfrac{2}{3}$$

$$\text{or }y=\tfrac{2}{3}x+8$$

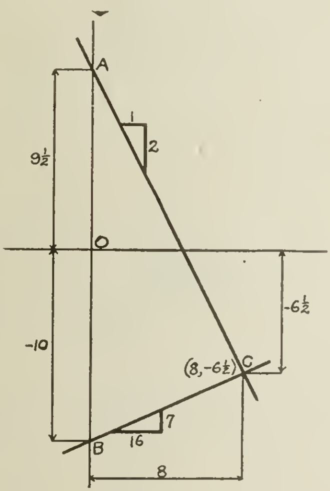


Fig. 6

Fig. 6 represents the graphical solution of the two simultaneous equations

$$4x+2y=19$$
$$7x-16y=160$$

The equations may be written in the slope form

$$y=-2x+9\tfrac{1}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$
$$y=\tfrac{7}{16}x-10 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

To draw the line representing equation (1), lay off OA equal $9\frac{1}{2}$ units and draw the line AC through A having a negative slope 2.

The line BC representing equation (2) having a positive slope $\frac{7}{16}$ is drawn through the point B where the intercept is —10. The two lines intersect at C, for which the co-ordinates are (8, —6½). Since C is a common point of both lines, the values of x and y for this point must satisfy the equation of each line. Hence $x=8$ and $y=-6\frac{1}{2}$ is the solution of the two equations.

A quadratic equation is usually solved by the process of "completing the square." For example, to solve the equation

$$x^2-3x-10=0$$

write the equation in the form

$$x^2-3x=10$$

By adding 9/4, which is the square of half the coefficient of x to both members, the left hand member becomes a perfect square.

$$x^2-3x+\frac{9}{4}=\frac{49}{4}$$

Extract the square root of both members

$$x-\frac{3}{2}=\pm\frac{7}{2}$$

$$\text{or } x=5 \text{ or } -2$$

Each of these values satisfies the original equation and they are called the roots of the equation.

A graphical solution is shown in Fig. 7. The equation may be written in the form

$$x^2=3x+10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

and each member expressed as a function of y thus:

$$y=x^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$
$$y=3x+10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The curve representing equation (4) may be drawn by assuming values of x and computing the corresponding values of y, thus

when $x=0$, $y=0$
$x=\pm1$, $y=1$
$x=\pm2$, $y=4$
$x=\pm3$, $y=9$, etc.

The smooth curve AOB, drawn through the points thus located, is the graph of $y=x^2$. The line representing equation (5) intersects the curve AOB at C and D, where x equals 5 and —2, respectively, showing that $x=5$ or -2 are the roots of equation (3).

The equation $x^2-6x+9=0$ has but one root, $x=3$. The

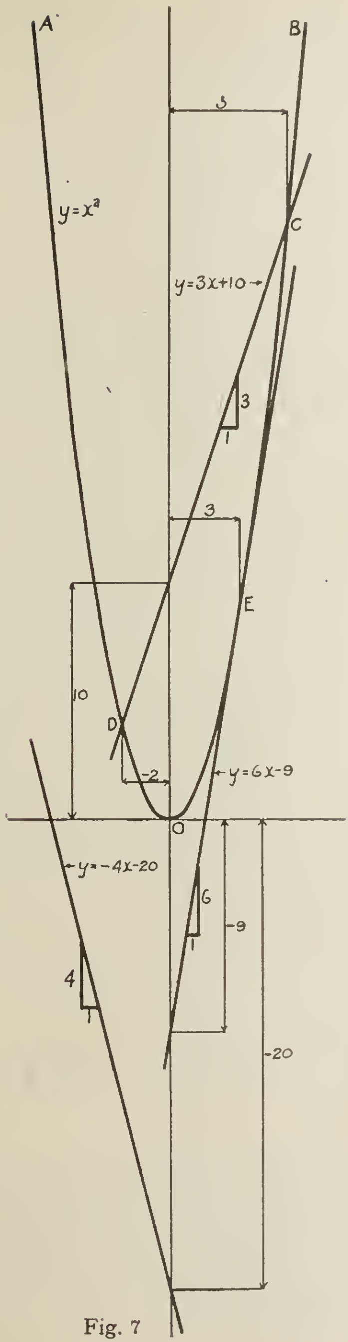


Fig. 7

graphical solution illustrates this fact by showing that the line $y = 6x - 9$ does not intersect the curve AOB, but simply touches it at one point E for which $x = 3$.

Let us attempt a solution of the equation

$$x^2 + 4x + 20 = 0 \quad \dots\dots\dots\dots (6)$$

Completing the square, we have

$$x^2 + 4x + 4 = -16$$

Extract the square root

$$x + 2 = \pm 4\sqrt{-1}$$

It is impossible to extract the square root of a negative quantity. Here we find imaginary values. There are then no real values for x which will satisfy equation (6).

The graphic counterpart of this solution is seen in Fig. 7. The line $y = -4x - 20$ has no common points with the curve $y = x^2$.

Graphical methods are very helpful in establishing approximate relations between quantities which do not vary in accordance with any mathematical law. Suppose that a designing engineer wishes to determine the relation between the length of span and the weight per foot for a class of railroad bridges, such as, for example, an E 50 loading, and in accordance with a certain specification. Undoubtedly he has a card index in which are recorded the shipping weights of several bridges of various lengths belonging to this particular class, from which the weight per foot is obtained for several lengths. This information is then plotted as shown in Fig. (8). For example, the point A records a bridge 105 feet long which weighs 2,050 pounds per foot. After all the data available have been plotted by points, a curve is drawn which will present as nearly as possible the average of these points. In the present case it is a straight line, intercepting the w axis at 600 lbs. per ft. and has a slope

$$\frac{1{,}300 \text{ lbs. per ft.}}{100 \text{ ft.}}$$

Let $(l, w.)$ represent the co-ordinates of any point on the line, then

$$w \text{ lbs. per ft.} = \frac{1{,}300 \text{ lbs.}}{100 \text{ ft.}^2}\, l \text{ ft.} + 600 \text{ lbs. per ft.}$$

$$\text{or } w = 13l + 600$$

The equation is a formula expressing the relation desired. This formula, like many others, has its limitations. While it may give sufficiently accurate results for determining the dead load to be used in a design of a span, the length of which is between the limits 100 feet and 250 feet, there is nothing whatever to guarantee its applicability to a span, say, 400 feet long.

A note of warning should be sounded whenever a formula, either rational or empirical, is presented for consideration or use. The history and limitation of the formula are essentials for an intelligent interpretation. It is usually the student who is weak in theory

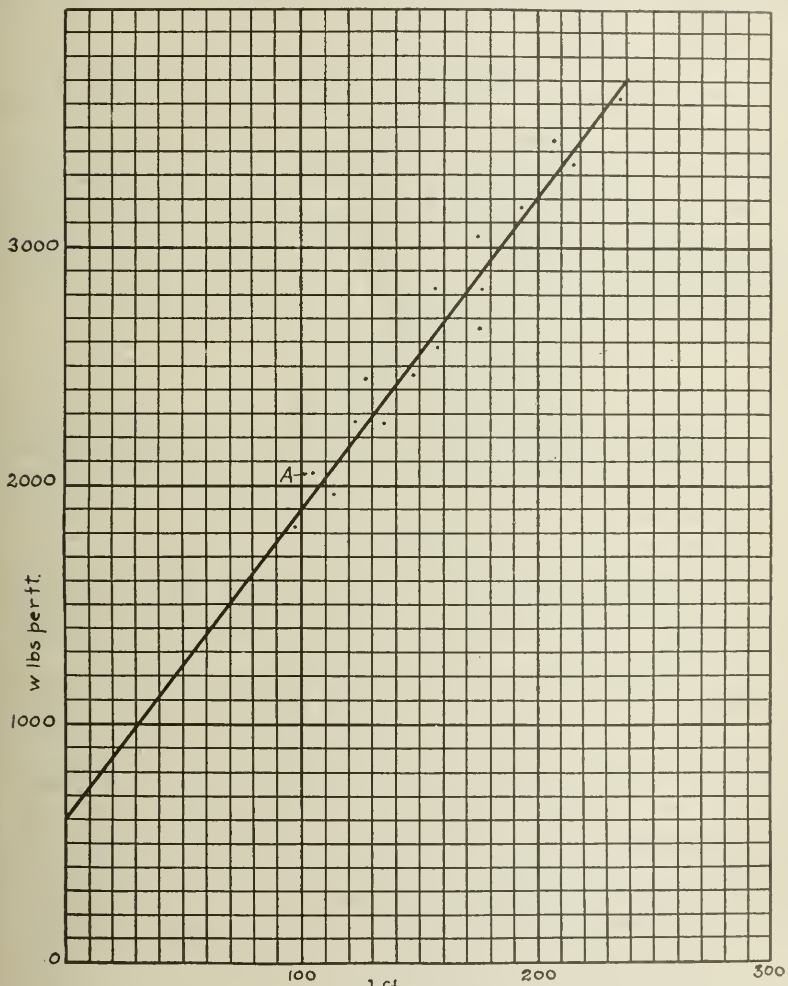


Fig. 8

who grasps for a formula as a drowning man for a straw; and his vain attempts to interpret the same should be a convincing argument against the formula method of teaching.

Let those who doubt this statement try the following experiment upon ten senior engineering students taken at random from any engineering college in the country: Consider a horizontal plank

of uniform cross section supported on edge at the ends and carrying a series of loads. Draw a vertical line on the beam at any point and a horizontal line either above or below the neutral plane. The young men will tell you that the bending stress at any point may be found by one of the formulas

$$s = \frac{Mc}{I} \text{ or } f = \frac{My}{I}$$

their choice depending on the text-book which they studied. Then ask them to name the constants and variables in the formula, as you move from point to point, first on the vertical and then on the horizontal line. Or ask them to state precisely what each symbol represents and in what units it is measured. You who believe in the formula method, try it.

In this connection the speaker is reminded of Willie:

Willie had an awful thirst,
But Willie is no more,
For what he thought was H_2O
Was H_2SO_4.

Whether the formula be rational or empirical, engineering or medical, it is a dangerous instrument except in the hands of experts.

CALCULUS

The fundamental concept of Differential Calculus is embodied in a clear understanding of the process of differentiation. Many can differentiate, but few appreciate what they are doing or why. Given the problem:

Differentiate $y = 2x - 0.2x^2$, and 95 per cent of third year engineering students will differentiate by rule or formula without hesitancy (and with little thought) and write $\frac{dy}{dx} = 2 - 0.4x$.

But the average student has little conception of what he has done or what use can be made of this differential equation. Now let us see if a graphical solution will help us any.

Let the curve *OAB* (Fig. 9) represent the graph of the equation $y = 2x - 0.2x^2$.

The curve is easily plotted by assigning values to x and computing the corresponding values of y thus:

$$\begin{array}{ll} x = 2 & y = 4 - 0.2 \times 4 = 3.2 \\ x = 3 & y = 6 - 0.2 \times 9 = 4.2 \\ x = 5 & y = 10 - 0.2 \times 25 = 5.0 \\ x = 8 & y = 16 - 0.2 \times 64 = 3.2, \text{ etc.} \end{array}$$

We may assume that the curve represents a hill 10 rods wide at the base and 5 rods high, over which a boy is running from O to B.

In the boy's journey from O to P we note that he has moved 3.2 rods vertically and 2 rods horizontally, the *average* ratio of the rise to horizontal distance is $\frac{3.2 \text{ rods}}{2 \text{ rods}} = 1.6$. In going from P to Q his horizontal distance from O increases from 2 rods to 3 rods, while his rise increases from 3.2 rods to 4.2 rods, and the *average* ratio of his rise to horizontal distance is $\frac{(4.2 - 3.2) \text{ rods}}{(3 - 2) \text{ rods}} = 1$. We note that the hill is not as steep from P to Q as from O to P. This ratio or slope is continually varying and is not the same for all portions of

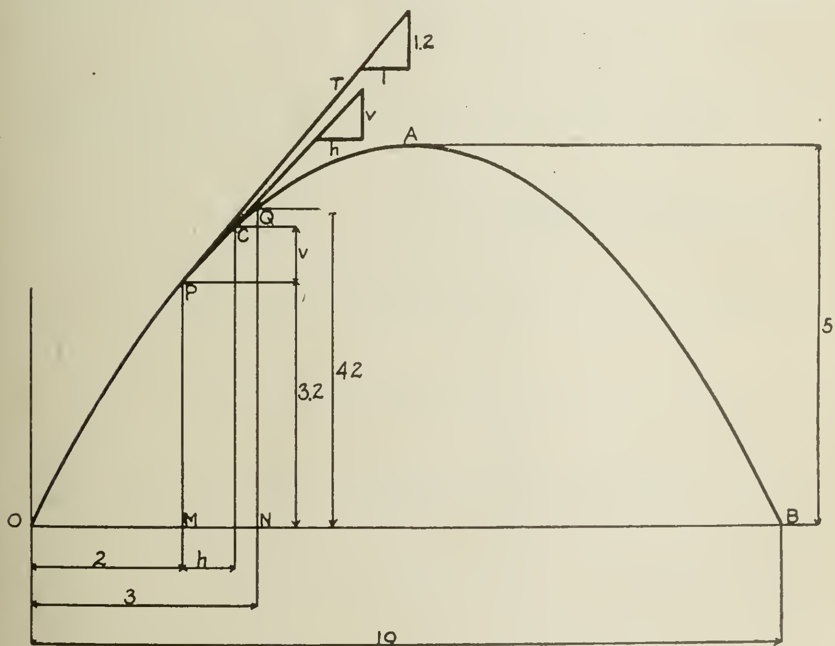


Fig. 9

the hill, as would be the case if the boy were running up an inclined straight platform or a flight of stairs.

Now suppose that we wish to know the value of this ratio for the *instant* when the boy is at P. More familiarly we wish to know the slope of a flight of stairs (represented by the line PT which touches the curve at P and at no other point) which has the same steepness as the hill at P.

Let us start another point C on a journey down the hillside

from Q to P. As C approaches P, the secant line through P and C grows steeper as it rotates about P and will coincide with the tangent line PT at the instant when C arrives at P.

The continually varying slope of the secant line PC is measured by the ratio $\dfrac{v}{h}$.

Since C is a point on the curve, the equation of which is $y = 2x - 0.2x^2$, we may establish a relation between v and h by placing $v + 3.2$ for y and $h + 2$ for x in the equation and obtain

$$v + 3.2 = 2\,(h + 2) - 0.2\,(h + 2)^2$$

Simplifying $v = 1.2h - 0.2h^2$

$$\text{or} \quad \frac{v}{h} = 1.2 - 0.2\,h \quad \dots\dots\dots\dots (1)$$

As C moves from Q to P, the value of h diminishes from 1 to 0. Let us assign a few numerical values to h in equation (1) and see what we get for the value of $\dfrac{v}{h}$.

$$\text{When } h = 0.8 \qquad \frac{v}{h} = 1.2 - 0.16 \quad = 1.04$$

$$h = 0.5 \qquad \frac{v}{h} = 1.2 - 0.1 \quad = 1.10$$

$$h = 0.1 \qquad \frac{v}{h} = 1.2 - 0.02 \quad = 1.18$$

$$h = 0.01 \qquad \frac{v}{h} = 1.2 - 0.002 \quad = 1.198$$

$$h = 0.001 \qquad \frac{v}{h} = 1.2 - 0.0002 = 1.1998$$

It is obvious that $\dfrac{v}{h}$ is approaching the value 1.2 as h is diminished.

As C approaches its limit P, the ratio $\dfrac{v}{h}$ approaches its limit-

ing value 1.2. We may suppose h to be as small as we please, in which case the ratio $\frac{v}{h}$ will differ as little as we please from 1.2. Now this value 1.2 is the limit toward which the ratio $\frac{v}{h}$ *approaches* as h diminishes, but which it can *never actually reach nor exactly equal.* Because in order that $\frac{v}{h}$ should *equal* 1.2, it is evident that $0.2h$ should equal zero. But when $0.2h$ equals zero, then h equals zero, v equals zero, *and we have no ratio at all.* This is the logical conclusion when our mathematical horizon is circumscribed by the arithmetical operations of addition, subtraction, multiplication and division. Now just at this point we are ready to consider the fundamental principle of the calculus, known as the *theory of limits,* which may be stated as follows:

If two variables are so related that as they change they keep always equal to each other, and each approaches a constant quantity as its limit, then their limits are absolutely equal.

This statement is almost axiomatic.

Two variables which are always equal cannot at the same time approach two constant quantities which are not equal.

We have two varying quantities, $\frac{v}{h}$ and $1.2 - 0.2h$, always equal to each other and at the same time approaching the value of two constant quantities. Hence the constant quantities must be equal. As h diminishes, the slope $\frac{v}{h}$ of the secant line PC is approaching its limit, the slope of the line PT, while $1.2 - 0.2h$ is approaching its limit 1.2. These two constant limits, then, must be equal. Hence the slope of the tangent line PT through P is 1.2.

It should be clearly understood and constantly kept in mind that no time does $\frac{v}{h}$ represent the slope of the tangent line PT. $\frac{v}{h}$ is the slope of the secant line PC in its varying positions. The

tangent line is in no sense, nor at any time, one of the series of secant lines; it is not the "last" secant line; it is a distinctly separate line, which has a special relation to the secant lines.

Having found the slope of the tangent line to the curve at a point definitely fixed by numerical values, let us consider the general case (Fig. 10) where P may represent *any* point on the curve

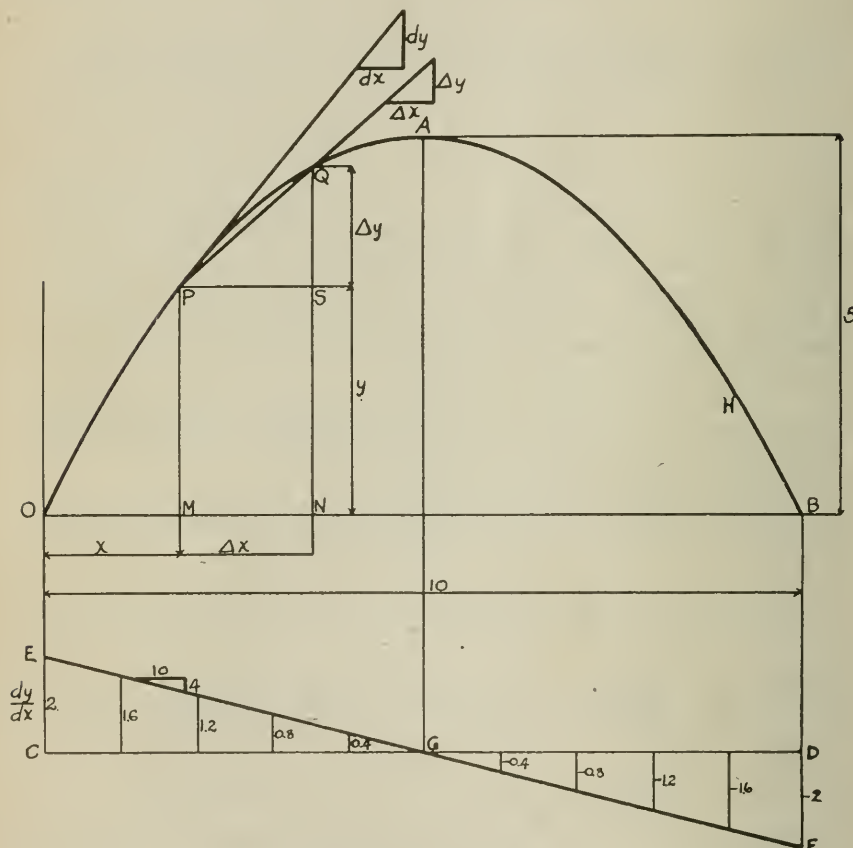


Fig. 10

$y = 2x - 0.2x^2$, where the abscissa OM has any value of x between the limits 0 and 10, for which there will be a corresponding value of y represented by PM. Now if x is increased by a quantity denoted by Δx and represented by MN, then y will be increased by a quantity denoted by Δy and represented by QS. The co-ordinates of any point Q, then, are $x + \Delta x$ and $y + \Delta y$. Since the point Q is on the curve we may substitute $x + \Delta x$ for x and $y + \Delta y$ for y in the equation $y = 2x - 0.2x^2$ and obtain

$$y + \Delta y = 2\,(x + \Delta x) - 0.2\,(x + \Delta x)^2.$$

Transposing and expanding,

$$\Delta y = 2x + 2\Delta x - 0.2x^2 - 0.4x\Delta x - 0.2\Delta x^2 - y.$$

But $y = 2x - 0.2x^2$

Substituting and reducing,

$$\Delta y = 2\Delta x - 0.4x\Delta x - 0.2\Delta x^2.$$

$$\text{or } \frac{\Delta y}{\Delta x} = 2 - 0.4x - 0.2\Delta x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Now suppose that the point Q is made to approach the point P by diminishing the distance Δx. $\frac{\Delta y}{\Delta x}$ representing the slope of the secant line QP and ever changing in value as Δx diminishes, always equals $2 - 0.4x - 0.2\Delta x$. As Δx is diminishing, the slope of the secant line PQ is approaching the slope of the tangent line PT as its limit, and the right-hand member of equation (2) which is always equal to $\frac{\Delta y}{\Delta x}$ is approaching its limiting value $2 - 0.4x$.

Hence the slope of the tangent line equals $2 - 0.4x$.

The limit of $\frac{\Delta y}{\Delta x}$ is called the differential coefficient of y with respect to x and is denoted by $\frac{dy}{dx}$. Hence we write $\frac{dy}{dx} = 2 - 0.4x =$ the slope of the tangent line through any point P the abscissa of which is x. The slope of the tangent line at any particular point on the curve may easily be obtained by the equation

$$\frac{dy}{dx} = 2 - 0.4x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Suppose we desire the slope of the tangent line at P (Fig. 9) where $x = 2$. Putting $x = 2$ in equation (3) we have

$$\frac{dy}{dx} = 2 - (0.4 \times 2) = 1.2$$

It follows, then, that the equation $y = 2x - 0.2x^2$ represented by the curve OAB (Fig. 10) may be differentiated graphically in

the following manner: Draw tangents to the curve OAB through points reasonably close together on the curve. Scale the slope $\dfrac{dy}{dx}$ of each tangent; plot the value on an ordinate directly below the point of tangency, and draw a smooth curve through the points thus plotted. The lower curve is called the derived curve of the upper one. In the present case the derived curve, drawn through points thus located, is the straight line EF the equation of which is $\dfrac{dy}{dx} = -0.4x + 2$ where the values of x are measured on the horizontal axis CD and the corresponding values $\dfrac{dy}{dx}$ are measured on its vertical axis CE.

The horizontal scale for the lower figure is the same as for the upper one. The vertical scales, however, have an entirely different meaning each from the other. In the upper figure the vertical scale represents an actual height as 3.2 rods or 5 rods, while in the lower figure the vertical scale of any ordinate represents a ratio which is the slope of the tangent through the corresponding point of the upper curve. Thus the slope of the tangent at O is $+2$; at H it is -1.6; and at B the slope is -2.

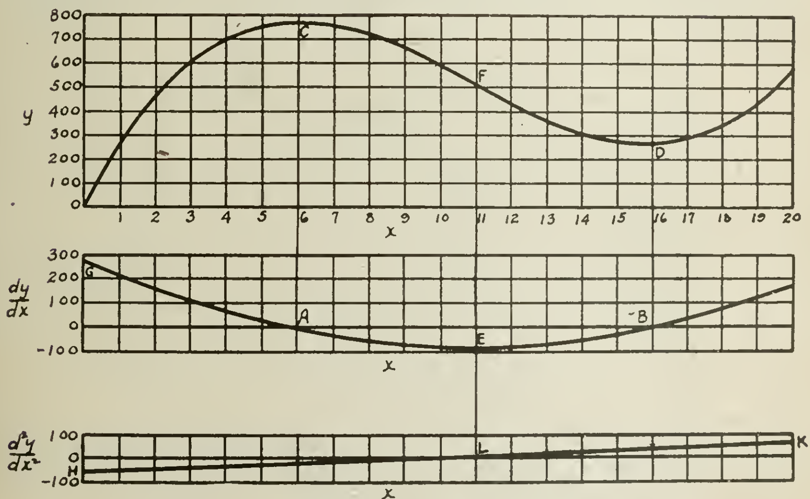
In his journey the boy will be going up-hill so long as his tangent line continues to slope upward to the right or as long as the $\dfrac{dy}{dx}$ ordinate remains a positive ratio. As he passes the top of the hill at A, the ordinate $\dfrac{dy}{dx}$ passes from a positive ratio, through zero, to a negative ratio; hence, the tangent to the curve ceases to slope upward to the right at the point A, where it is horizontal, and "tips the other way" as the point A is passed, and the boy begins to descend.

The value of y is a maximum at the high point of the hill where the value of $\dfrac{dy}{dx}$ equals zero, by passing from a positive to a negative ratio.

Fig. 11 represents a "hill and a valley" which is the graph of the equation $y = x^3 - 33x^2 + 288x$. Differentiating, we have

$\frac{dy}{dx} = 3x^2 - 66x + 288$, which is represented in Fig. 12. Equating $\frac{dy}{dx}$ to zero, gives $3x^2 - 66x + 288 = 0$. Solving for x, we have $x = 6$ or 16. Hence, we have two points A and B in Fig. 12 where $\frac{dy}{dx} = 0$.

At A where $x = 6$, $\frac{dy}{dx}$ equals zero by passing from a positive to a negative ratio, hence the tangent at C ceases to "slope up" and



Figs. 11, 12, 13

begins to "slope down," and we have a high point in the hill or a maximum value for y, while at the point B for which $x = 16$ the ratio $\frac{dy}{dx}$ passes from a negative to a positive value, and the tangent at D begins to "slope up" again, giving a low point in the hill or a minimum value for y.

The curve in Fig. 12 continues to slope downward from G to E; consequently the tangent to the curve (Fig. 11) continues to rotate clockwise as far as the point F. From the point E onward the curve in Fig. 12 slopes upward; hence the tangent rotates

counter-clockwise from the point F. In other words, the curve in Fig. 11 has a curvature in one direction preceding the point F and in the opposite direction beyond F.

If we differentiate the equation $\frac{dy}{dx} = 3x^2 - 66x + 288$, we shall have the "second derived equation," $\frac{d^2y}{dx^2} = 6x - 66$, which is represented in Fig. 13 by the line HK. Fig. 13 bears the same relation to Fig. 12 as Fig. 12 bears to Fig. 11. An ordinate in Fig. 12 gives the slope of the tangent to the curve in Fig. 11, and an ordinate in Fig. 13 gives the slope of the tangent to the curve in Fig. 12; hence, the ordinates in Fig. 13 give the *rate* at which the tangents to Fig. 11 are varying. The ordinates in Fig. 13 represent the curvature of Fig. 11. F is the point of inflection and the curva-

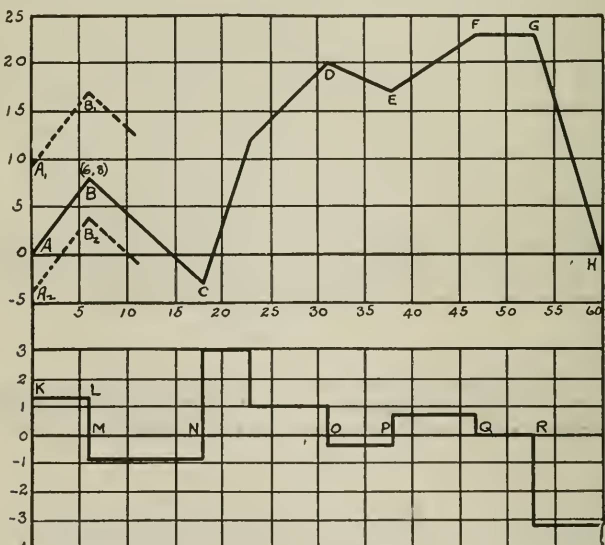


Fig. 14

ture near F is slight as the curve approaches a straight line, since the ordinates near L are approaching zero.

It is not essential that our primary curve shall be a continuous function from end to end in order that the derived curve may be drawn. We might consider a series of broken straight lines (Fig. 14), such as several flights of stairs and a level platform to provide passage over a somewhat irregular route. It is at once apparent that the flights have diffeent slopes; some are steeper than others.

We shall gage their steepness by drawing a curve, the ordinates of which will measure their slope. The flight AB has a positive slope

$$\frac{8 \text{ feet}}{6 \text{ feet}} = \frac{4}{3},$$ hence the line KL having a positive ordinate 4/3 is the derivative of the line AB.

Beyond B the rise instantly changes into a fall and the ordinate of the lower curve instantly becomes negative. At the points M and O the derived curve passes through zero from a positive to a negative ordinate, and, therefore, at the points B and D we may expect to find high points or maximum ordinates in our primary curve. Similarly at N and P the derived curve passes through zero from a negative to a positive ordinate, and we find low points or minimum ordinates at C and E. When the student is asked to describe what is meant by the maximum value of a function, his

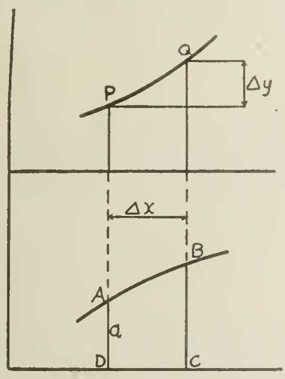


Fig. 15

customary reply is as follows: "It is the largest value we can get." Of course, this reply is entirely erroneous. A maximum ordinate is not necessarily long, nor is a minimum ordinate essentially short. A minimum ordinate may be longer than a maximum ordinate as is the case in comparing the maximum ordinate at B with the minimum ordinate at E.

A maximum value of a function is that value which is greater than the value which immediately precedes or follows it. Thus, the ordinate at D is longer than the one just to the left or right, hence the ordinate at D is a maximum. We note that the derived curve is zero from Q to R, hence that portion of the primary curve from F to G, having a zero slope, is consequently horizontal and the length of the ordinate is constant from F to G. The differential coefficient of a constant is zero.

Now let us consider the converse process. Suppose we have given the derived curve or curve of slopes and wish to construct the curve representing the actual elevation of our stairs. Since the

ordinates to the derived curve from K to L are constant, positive, and equal 4/3, we see that the first flight must be straight having a positive (up to the right) slope 4/3. The line AB complies with these conditions, but so also does any other line which may be drawn parallel to AB, thus having the same slope as AB, as A_1B_1, for example, or A_2B_2. We are at once confronted with a very important question, Where shall we begin to draw the line AB? It must be admitted that there is nothing in our derived curve to tell us where the starting point is located on the vertical line, whether at A, A_1, A_2, or some other point. The conditions of our problem will be met if any set of lines is drawn parallel to ABC..........H either above or below.

This intercept on the y axis which locates the starting point, corresponds to the *constant of integration* of the algebraic process.

The equation of the line AB is $y = 4/3x$.................(1)
The equation of the line A_1B_1 is $y = 4/3x + 9$............(2)
The equation of the line A_2B_2 is $y = 4/3x - 4$............(3)

Differentiating equation (1) we have $\dfrac{dy}{dx} = 4/3$.........(5)

represented by the line KL, which is also the differential equation of equations (2) and (3), since the differential coefficient of a constant is zero. Hence, if we integrate equation (5) we have $y = 4/3x +$ a constant. This constant may be 9 or -4 or 108 or any other number, unless further information is given. The determination of this constant term will be considered later.

One other important relationship may be established between the primary and derived curves. In Fig. 15 let AB represent the derived curve or curve of slopes of the upper one, PQ; hence, the ordinate a measures the slope of the tangent through P.

Now, as $\triangle x$ diminishes,

$$\frac{\triangle y}{\triangle x} \text{ approaches the value } a$$

or $\triangle y$ approaches the value $a\triangle x$.

Also as $\triangle x$ diminishes, the area $ABCD$ approaches the value $a\triangle x$. Hence the two variables $\triangle y$ and the area $ABCD$, which are approaching the same limit, must be equal, and we have

$$\triangle y = \text{area } ABCD.$$

That is, *the difference in lengths of any two ordinates in the primary or integral curve equals the area bounded by these two ordinates, the horizontal axis and the derived curve.*

SHEAR AND MOMENT DIAGRAMS

Before we give our attention to shear and bending moment problems, it will be well to have a clear notion of what an engineer means by the terms shear and bending moment.

The shearing force at any normal section of a beam is the algebraic sum of all the transverse forces acting on one side (either side) of the section. When this sum or the resulting force acts upward on the left of the section, call it positive; when downward, negative.

The bending moment at any normal section of a beam is the algebraic sum of the moments of all the forces acting on one side (either side) of the section, taken about the center of gravity of the section as an axis. When this sum or the resulting moment is clockwise on the left of and about the section, call it positive; when counter-clockwise, call it negative.

Fig. 16 shows a beam supporting a uniform load of w pounds per foot and four concentrated loads, W_1, W_2, W_3 and W_4. Let

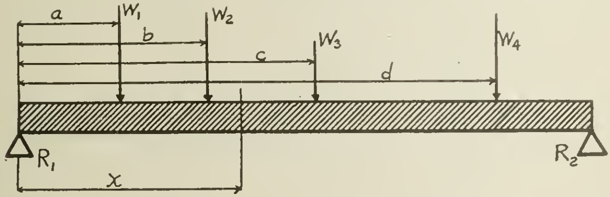


Fig. 16

R_1 and R_2 represent respectively the left and right reactions. The shear at any section—say between W_2 and W_3, which is a distance x from the left support—is $S = R_1 - W_1 - W_2 - wx$, and the bending moment is $M = R_1x - W_1(x-a) - W_2(x-b) - \frac{wx^2}{2}$.

Differentiating M with respect to x, $\frac{dM}{dx} = R_1 - W_1 - W_2 - wx$.

And we note that $\frac{dM}{dx} = S$. This shows that the moment and shear curves have the relation of primary and derived curves.

If we draw the moment curve and differentiate it graphically, the shear curve will be the result. Or if the shear curve or curve of slopes is drawn first we may obtain the moment curve by graphical integration.

Consider a simple beam having a span of 20 feet with loads and reactions as shown in Fig. 17. The shear curve will be drawn

first because it is the simpler of the two. Draw vertical lines through the location of the loads and reactions. Let O_1X_1 and O_1S be the axes for the shearing forces. For any section between the left support and the first load the shearing force is +5 pounds. On O_1S lay off to any convenient scale the ordinate $OA = 5$ lbs. and draw AB parallel to O_1X_1. On the ordinate through B, lay off downward $BC = 2$ lbs. and draw CD. Continue in like manner to the right support. The broken line $O_1ABC \ldots\ldots GX_1$ is the shear curve since the measure of any ordinate of the curve gives the shear at the corresponding section of the beam.

We now proceed to draw the moment curve by a graphical integration of the shear curve. This is accomplished by drawing a curve wherein the slope at any point equals the ordinate or height

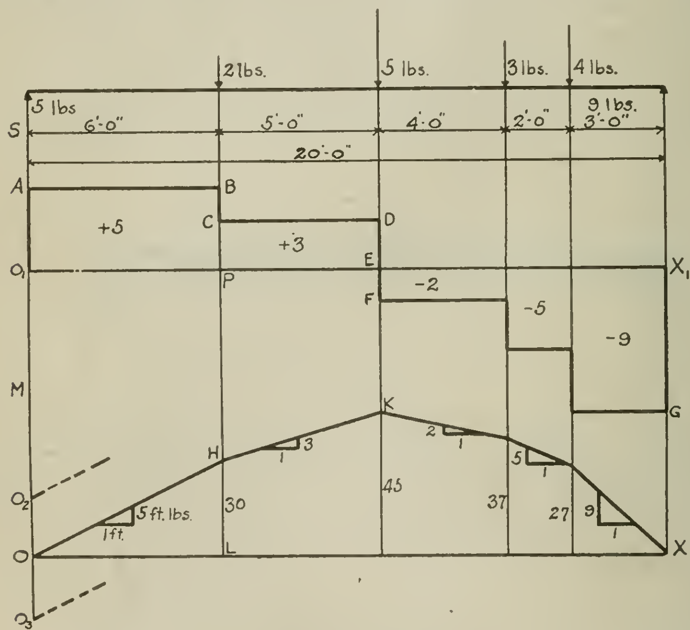


Fig. 17

of the shear curve at the corresponding point. The axes are OX and OM. The horizontal scale of the abscissæ is the same as for the shear curve. The unit of measure for the ordinates is a foot-pound for which any convenient scale is chosen. The ordinate in the shear curve from A to B is constant, positive, and equals 5 lbs.; hence our moment curve begins with a straight line of positive slope

$$\frac{5 \text{ ft. lbs. vertical}}{1 \text{ ft. horizontal}} = 5 \text{ lbs.}$$

Again, as in Fig. 14, we are confronted with the question:

Where shall we start the line, at O, O_2 or O_3? Or, in other words: What is our constant of integration?

From our definition of bending moment we find that the moment at either end of this beam is zero, hence the height of the curve on the ordinate OM is zero, and the line OH having the proper slope is drawn. The line HK has a positive slope 3 lbs. At E the upper curve passes through zero from positive to negative shear, consequently the moment curve, in changing from positive to negative

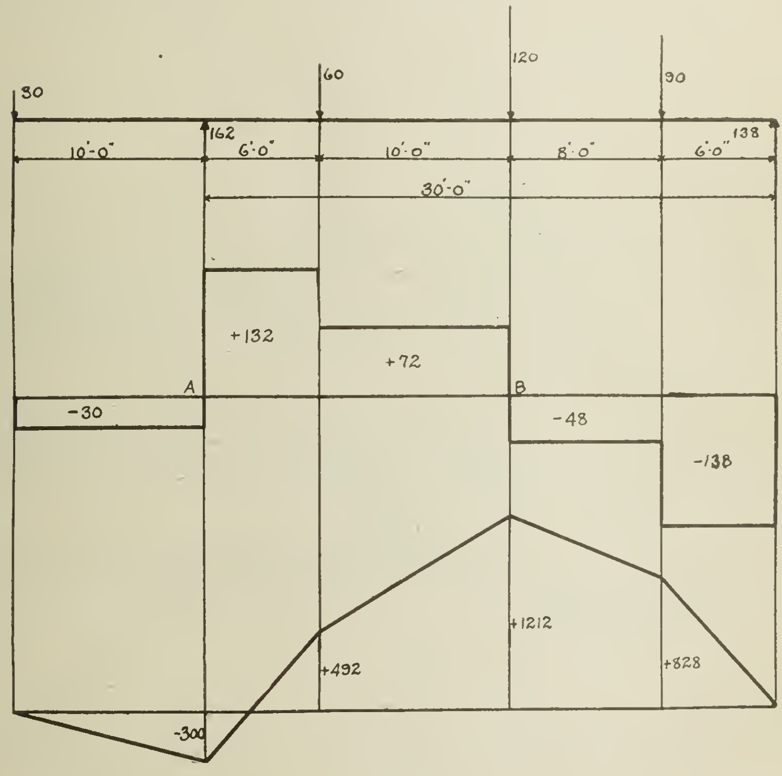


Fig. 18

slope, reaches a maximum at K. The remaining portion of the curve or diagram is similarly drawn.

It was shown in Fig. 15 that the difference in length of any two ordinates in the primary or integral curve equals the area bounded by the two ordinates, the horizontal axis and the derived curve. Then the area O_1ABP, which may be considered as the product of $+5$ lbs. and 6 ft. or $+30$ ft.-lbs., is the difference in length of the ordinates at O and L.

The ordinate LH, then, is $+30$ ft.-lbs. since the ordinate at O

is zero. The consecutive ordinates are easily calculated as follows:

$$
\begin{array}{rr}
 & 0 \\
+5\times 6 = & +30 \\
\hline
 & +30 \\
+3\times 5 = & +15 \\
\hline
 & +45 \\
-2\times 4 = & -8 \\
\hline
 & +37 \\
-5\times 2 = & -10 \\
\hline
 & +27 \\
-9\times 3 = & -27 \\
\hline
 & 0
\end{array}
$$

This method of calculation checks itself, being particularly helpful when the shear and moment diagrams are simply sketched and not drawn to scale.

The shear and moment diagrams for a cantilever beam are shown in Fig. 18. At A the shear curve passes through zero from positive to negative, causing a minimum, or maximum negative moment; while at B the shear changes from positive to negative and we have a maximum positive moment.

A maximum or minimum moment will always be found at the points of zero shear. Whether the moment is a maximum or minimum depends on the manner in which the shear passes through zero. The calculations follow:

$$
\begin{array}{rr}
 & 0 \\
-\ 30\times 10 = & -300 \\
\hline
 & -300 \\
+132\times 6 = & +792 \\
\hline
 & +492 \\
+\ 72\times 10 = & +720 \\
\hline
 & +1212 \\
-\ 48\times 8 = & -384 \\
\hline
 & +828 \\
-138\times 6 = & -828 \\
\hline
 & 0
\end{array}
$$

Now let us consider a beam (Fig. 19) 16 feet long supporting the uniform load 200 lbs. per foot. The shear curve starts with a positive ordinate 1,600 lbs. which decreases uniformly 200 lbs. in each foot from O_1 to C. Beyond C the negative ordinates increase to —1600 at X_1. The positive ordinates of the shear curve are continually decreasing; hence, the slope of tangents to the moment curve must decrease accordingly. At C the shear ordinate is zero, consequently at K the tangent to the curve is horizontal and the maximum moment occurs. Beyond K the tangents have an increasing negative slope.

Since the moment ordinate is zero at O, the length of an ordinate 4 ft. from O is the area O_1ABF or $\dfrac{1600 + 1800}{2}$ lbs. times 4 ft. = 4800 ft.-lbs. The maximum ordinate at K is the area O_1AC = 6400 ft.-lbs. The ordinate PQ equals the total shear area

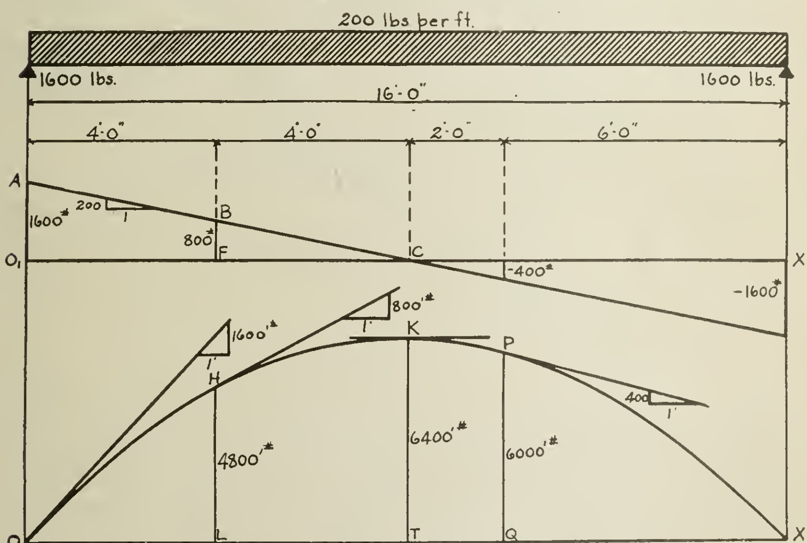


Fig. 19

from O_1 to G or 6400 ft.-lbs. minus 400 ft.-lbs. = 6000 ft.-lbs. The moment curve OKX is a parabola. The parabolic curve deserves more than a passing notice since it is more useful to the structural engineer than any other conic section.

THE STRUCTURAL ENGINEER'S PARABOLA

First impressions are lasting, is an aphorism which may well be applied to this very important curve. We usually think of the parabola as representing the equation $y^2 = 4ax$ or $4px$ or 4 some-

thing or other x— our concept depending upon the particular text-book used in our study of Analytic Geometry. Frequently a student will go so far as to say that the equation of a parabola is $y^2 =$ a constant times x, but it remains for the *rara avis* of the class to reconcile the equation $y^2 = kx$ with the bending moment diagram of a uniformly loaded beam. And the reason is found in the point of view.

Just what we mean by the point of view is best illustrated by a story about two men in a field, to say nothing of the dog (with apologies to J. K. J.). Two hunters, a mathematician and an en-

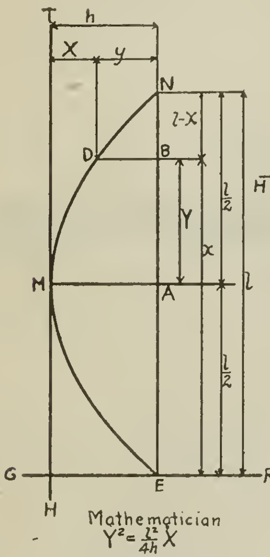


Fig. 20

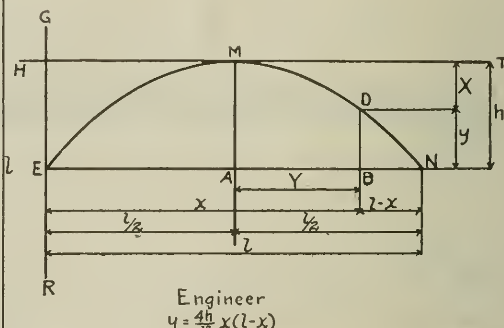


Fig. 21

gineer, are interested in the peculiar movements of a dog which is running along a path represented by the curve *EMN* (Fig. 20 or 21). The mathematician is observing the trail of the dog relative to two fences represented by the lines *MA* and *TH*, which intersect at right angles at the point *M* where he is standing. He notes that the dog runs so that the square of his distance from the fence *MA* when divided by his distance from the fence *TH* always gives the same quotient. In other words, if $\pm Y$ represents the dog's distance from *MA* and $+X$ his distance from *TH* when he is at *any* point *D* in his journey, then $\frac{Y^2}{X} =$ a constant quotient. The mathematician designates this quotient by the symbol k and writes

$$\frac{Y^2}{X} = k \text{ or } Y^2 = kX \dots\dots\dots\dots (1)$$

and he remembers that, while X and Y represent varying distances depending on the position of the dog, k never changes so long as

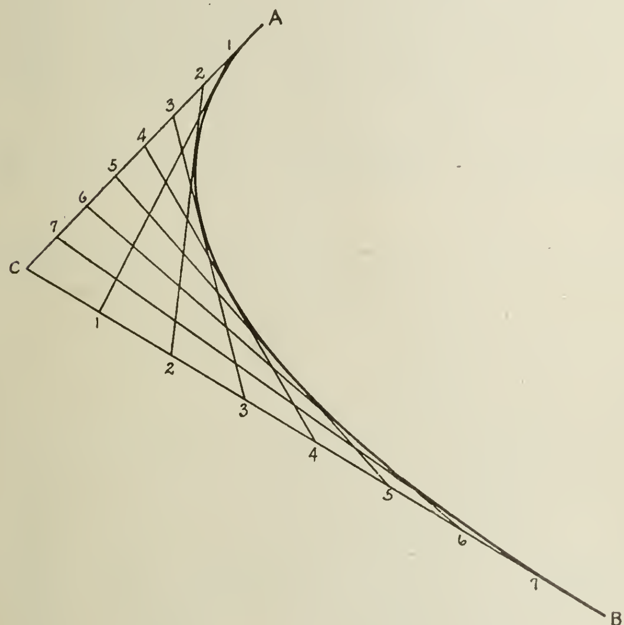


Fig. 22

the dog remains in the path EMN. Now when the dog D arrives at N, the mathematician has definite values for the variable distances represented by X and Y. He knows that $Y = \frac{l}{2}$ and $X = h$, and by substituting these values in equation (1), he has

$$\left(\frac{l}{2}\right)^2 = kh$$

or $k = \frac{l^2}{4h}$, which is the value of his constant quotient. So he writes $Y^2 = \frac{l^2}{4h} X \dots\dots\dots\dots (2)$

The engineer is also observing the movements of the dog; but he wishes to refer the dog's position at any instant to two other fences *EN* and *GR*, which are at right angles respectively to *MA* and *TH*, and intersect at *E* where he is stationed. So, taking the two symbols x and y, he lets them represent two variable distances. He designates the dog's distance from *EN* by y and his distance from *GR* by x, and then compares notes with his friend, the mathematician. They find that the sum of the two variable distances represented by X and y always equals the constant distance represented by h. They also note that the difference in the two variable distances represented by x and Y always equals the constant distance represented by $\dfrac{l}{2}$. Hence they write $X+y=h$ and $x-Y=\dfrac{l}{2}$ or $X=h-y$ and $Y=x-\dfrac{l}{2}$ and substitute these values in equation (2) and get

$$\left(x-\frac{l}{2}\right)^2=\frac{l^2}{4h}(h-y)$$

which, when simplified, reads $y=\dfrac{4h}{l^2}x(l-x)$ . . . . (3)

This is the engineer's equation of this particular curve in the same sense as equation (2) is the mathematician's equation. The fact that the two men are looking at the curve from different points of view, and are referring their observations to different base lines, accounts for the difference in form of two equations for the same curve.

When the student is introduced to the parabola, it is always dressed in the fashion of equation (1) and, we repeat, first impressions are lasting.

Equation (3) may be transformed so as to read

$$\frac{y}{h}=\frac{x\,(l-x)}{\left(\frac{l}{2}\right)\left(\frac{l}{2}\right)}$$

from which we make the following exceedingly important observation in Fig. 21: The ordinates *DB* and *MA* are to each other respectively as the products of the two parts into which each divides the line *EN*.

This fact gives a clue to the very simple method of locating points on a parabolic curve. Suppose we wish to locate, say, seven points through which a parabola will pass when constructed on the

line OX, Fig. 19. Divide the line OX into eight equal parts. The ordinate at each point is proportional to the product of the number of parts on either side of it; and we write the several products thus:

$$
\begin{aligned}
1 \times 7 &= 7 \\
2 \times 6 &= 12 \\
3 \times 5 &= 15 \\
4 \times 4 &= 16 \\
5 \times 3 &= 15 \\
6 \times 2 &= 12 \\
7 \times 1 &= 7
\end{aligned}
$$

Now, if we wish the middle ordinate to equal 6400 instead of 16, we simply multiply that ordinate and all the others by 400 and we have

$$
\begin{aligned}
7 \times 400 &= 2800 \\
12 \times 400 &= 4800 = HL \\
15 \times 400 &= 6000 \\
16 \times 400 &= 6400 = KT \\
15 \times 400 &= 6000 = PQ \\
12 \times 400 &= 4800 \\
7 \times 400 &= 2800
\end{aligned}
$$

It is frequently desired to construct a parabola which is tangent to two given intersecting lines. Suppose we have the two

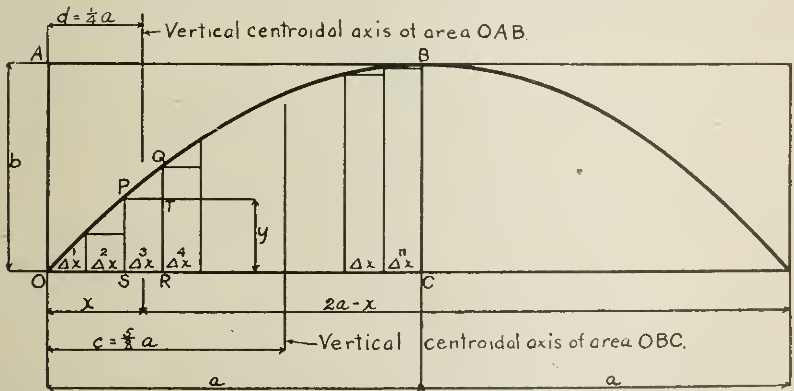


Fig. 23

tangents AC and BC (Fig. 22) and the points of tangency A and B. Divide AC and BC by points into the same number of equal parts. Number the points from A to C and from C to B. Connect 1-1, 2-2, etc. A parabolic curve lies tangent to these lines as shown.

There are two other properties of the parabola which are of frequent use to the structural engineer. (1) The areas into which a parabola divides a circumscribed rectangle and (2) the centroids of these areas.

(1) Area of Segments.—Suppose we wish the area OBC (Fig. 23) where OB is a parabola with its vertex at B. Any ordinate y

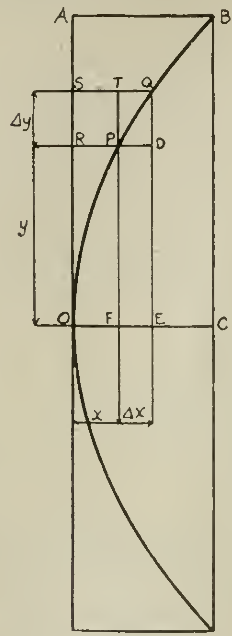


Fig. 24

is to any other ordinate b as the product of x and $2a - x$ is to the product of a and a, or $\dfrac{y}{b} = \dfrac{x\,(2a - x)}{a^2}$, whence

$$y = \frac{b}{a^2}\,x\,(2a - x) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

is the equation of the parabola.

Suppose that ordinates are drawn which divide the area OBC into n elements of equal width $\triangle x$, then

$$n \triangle x = a$$

Let $PQRS$ represent any one of these elements and $PTRS$ the corresponding rectangle. The area of the rectangle is

$$y \triangle x = \frac{b}{a^2}\,x\,(2\,a - x)\triangle x = \frac{2\,b}{a}\,x \triangle x - \frac{b}{a^2}\,x^2 \triangle x$$

If the number of elements is indefinitely increased by diminishing

Δx, then the limit of the area of any rectangle is the area of the corresponding element.

Now the sum of all the elements is the area OBC; hence we have only to find the *limit of the sum* of all the rectangles in order to obtain the area sought. In other words, we must find the limit of the *sum* of $\frac{2b}{a} x \Delta x - \frac{b}{a^2} x^2 \Delta x$ for all the different values of x. There are, of course, n different and consecutive values for x, from o to a, or one for each element. These consecutive values are

$$\Delta x, 2 \Delta x, 3 \Delta x \ldots\ldots\ldots\ldots n \Delta x$$

Let S represent the sum of the rectangles; then

$S =$ the sum of $\left[\frac{2b \Delta x}{a}\right] x - \left[\frac{b \Delta x}{a^2}\right] x^2$ for all the values of x. The sum of the consecutive values of x is

$$\Delta x (1 + 2 + 3 + \ldots\ldots n) = \Delta x \left[\frac{n(n+1)}{2}\right]^*$$

The sum of the consecutive values of x^2 is

$$\Delta x^2 (1 + 4 + 9 + \ldots\ldots\ldots n^2) = \Delta x^2 \left[\frac{n(n+1)(2n+1)}{6}\right]^\dagger$$

$$\text{Hence } S = \left[\frac{2b \Delta x}{a}\right] \Delta x \left[\frac{n(n+1)}{2}\right]$$

$$- \left[\frac{b \Delta x}{a^2}\right] \Delta x^2 \left[\frac{n(n+1)(2n+1)}{6}\right]$$

$$S = \frac{2b}{a} \cdot \frac{n^2 \Delta x^2 + n \Delta x^2}{2}$$

$$- \frac{b}{a^2} \cdot \frac{2n^3 \Delta x^3 + 3n^2 \Delta x^3 + n \Delta x^3}{6}$$

But $n \Delta x = a$.

*To illustrate suppose $n = 4$

Then $1 + 2 + 3 + 4 = \frac{4(4+1)}{2} = 10.$

†Suppose $n = 4$

Then $1 + 4 + 9 + 16 = \frac{4(4+1)(8+1)}{6} = 30.$

Therefore $S = \frac{2b}{a}\,\frac{a^2 + a \triangle x}{2} - \frac{b}{a^2} \cdot \frac{2a^3 + 3a^2 \triangle x + a \triangle x^2}{6}$

$$S = ab + b \triangle x - \frac{1}{3} ab - \frac{1}{2} b \triangle x - \frac{b}{6a} \triangle x^2$$

Finally $\quad S = \frac{2}{3} ab + \frac{1}{2} b \triangle x - \frac{b}{6a} \triangle x^2 \ldots\ldots\ldots\ldots\ldots\ldots (2)$

However small $\triangle x$ may be or however great, the two variables, S and its value, will always represent the sum of the areas of the rectangles. As $\triangle x$ diminishes and the number of rectangles increases, the area S of the rectangles approaches the area OBC, likewise the right hand member of equation (2) approaches the value $\frac{2}{3} ab$. And since the two members of equation (2) are always equal and approaching certain limits, their limits must be equal, therefore,

area $OBC = \frac{2}{3} ab$, and area $OAB = ab - \frac{2}{3} ab = \frac{1}{3} ab$.

Again we must affirm in words that cannot be misunderstood that, however narrow or numerous the rectangles may become, their sum can never *equal* the area OBC. Their sum will always remain less than the area OBC by the amount $\frac{1}{2} b \triangle x - \frac{b}{6a} \triangle x^2$. Of course, this amount decreases and approaches zero, as the rectangles diminish in width, but can never equal zero unless $\triangle x$ equals zero, when we should have no rectangles at all. The rectangles would have shrunk to vertical lines which have no width. It is as impossible to grow areas from straight lines which have no width as to create lines from any number of points which have no length.

Another and somewhat shorter proof of this proposition is worthy of note. The equation of the parabola (Fig. 24) is $y^2 = kx$, when the vertex is at the orgin O. Since the point Q is on the curve,

$$(y + \triangle y)^2 = k(x + \triangle x)$$

which may be reduced

$$\frac{\triangle y}{\triangle x} = \frac{k - \triangle x}{2y}$$

$$\frac{\text{Area } PRST}{\text{Area } PDEF} = \frac{x \triangle y}{y \triangle \text{x}} = \frac{x\,(k - \triangle x)}{2\,y^2} = \frac{k\,x - \triangle x}{2\,k\,x}$$

As $\triangle x$ diminishes, this ratio approaches the value ½ and as this is equally true for any pair of rectangles, it follows that the area OAB is one-half the area OBC.

(2) Centroidal axis of area OBC—Let c (Fig. 23) represent the distance from OA to the vertical centroidial axis of area OBC; and let M represent the moment of the area OBC about the line OA;

then $M = \dfrac{2}{3}\,a\,b\;.\;\text{c.}$

The moment of the area of any rectangle $PTRS$ about the line OA is

$$x\,y \triangle x = \frac{2\,b}{a}\,x^2 \triangle x - \frac{b}{a^2}\,x^3 \triangle x$$

and we have to find the *limit of the sum* of the moments of all the rectangles for all the values of x.

Let N represent this sum, then

$$\text{N} = \text{sum of} \left[\frac{2\,b \triangle x}{a}\right] x^2 - \left[\frac{b \triangle x}{a^2}\right] \quad x^3$$

for all values of x.

This sum of the consecutive values of x^2 is

$$\triangle x^2\,(1 + 4 + 9 + \ldots\ldots n^2) = \triangle x^2 \left[\frac{n\,(n+1)\;\;(2\,n+1)}{6}\right]$$

The sum of the consecutive values of x^3 is

$$\triangle x^3\,(1 + 8 + 27 + \ldots\ldots\ldots n^3) = \triangle x^3 \left[\frac{n\,(n+1)}{2}\right]^{2\,*}$$

$$\text{Hence N} = \left[\frac{2\,b \triangle x}{a}\right] \triangle x^2 \left[\frac{n\,(n+1)\;\;(2\,n+1)}{6}\right]$$
$$-\left[\frac{b \triangle x}{a^2}\right] \triangle x^3 \left[\frac{n\,(n+1)}{2}\right]^2$$

Simplifying and substituting a for $n \triangle x$.

$$N = \frac{b}{3\,a}\,(2\,a^3 + 3\,a^2 \triangle x + a \triangle x^2)$$

*Suppose $n = 4$

Then $1 + 8 + 27 + 64 = \left[\dfrac{4(4+1)}{2}\right]^2 = 100$

$$-\frac{b}{4a^2}(a^4 + 2a^3 \triangle x + a^2 \triangle x^2) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

As $\triangle x$ diminishes the moment N of the rectangles approaches the moment M of the area OBC, and the right hand member of equation (3) approaches the value

$$\frac{b}{3a} \cdot 2a^3 - \frac{b}{4a^2} a^4 .$$

Hence $M = \dfrac{b}{3a} \cdot 2a^3 - \dfrac{b}{4a^2} a^4 = \dfrac{5}{12} a^2 b$

and the distance of the centroidal axis from O is

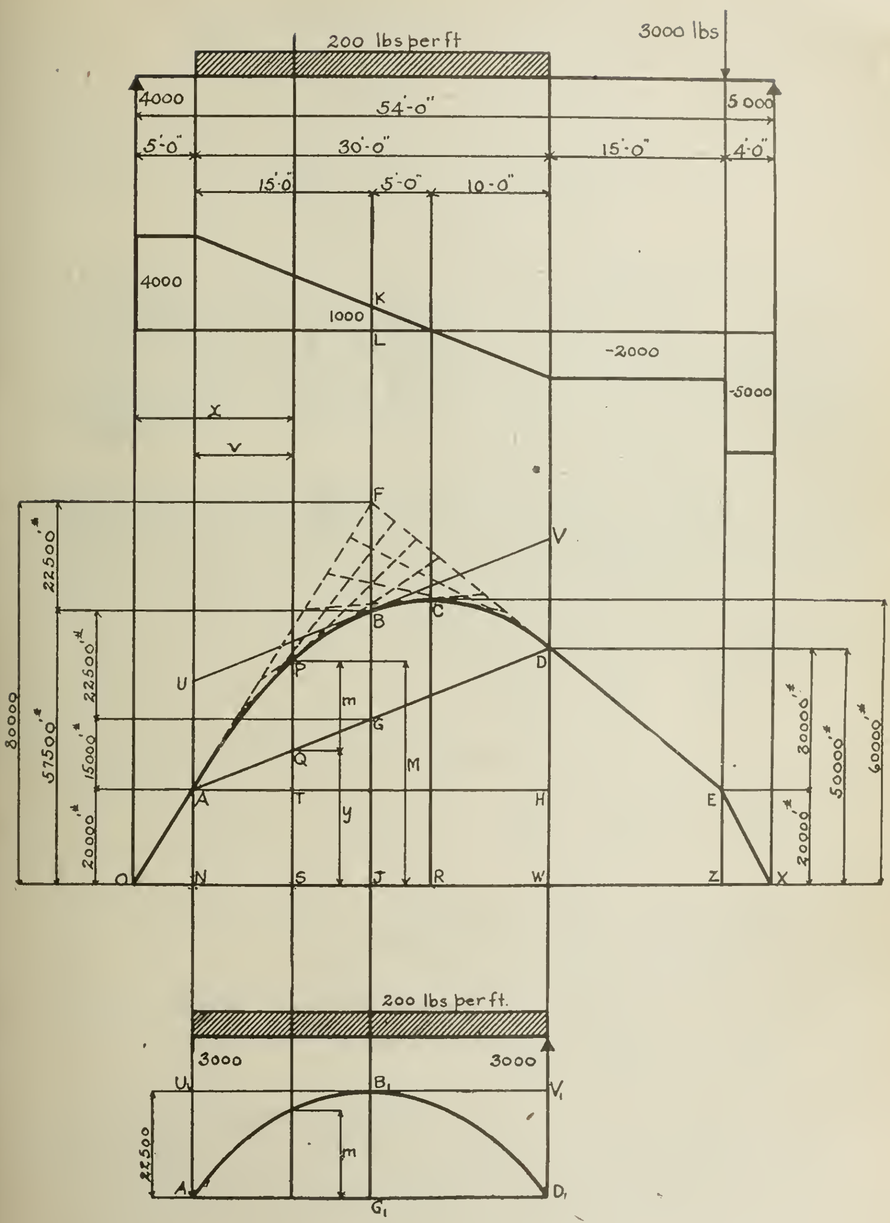
$$c = \frac{M}{\frac{2}{3} a b} = \frac{5}{8} a$$

The moment of the rectangle $OABC$ about OA is $ab \dfrac{1}{2} a = \dfrac{a^2 b}{2}$.

Let d represent the distance from OA to the centroidal axis of the area OAB, then $d \dfrac{ab}{3} + c \dfrac{2ab}{3} = \dfrac{a^2 b}{2}$. Whence $d = \dfrac{1}{4} a$.

The shear and moment diagrams for a beam which carries a uniform load over a portion of its length (Fig. 25) have several interesting properties. Integrating the shear curve we find that the moment curve is represented by the line OA, the parabola $ABCD$, and the lines DE and EX. Summing the areas in the shear diagram, we have

$$\begin{array}{rl}
 & 0 \quad \text{at } O \\
+4000 \times 5 = & +20000 \text{ ft. lbs.} \\
\hline
 & +20000 \text{ ft. lbs.} = AN \\
\dfrac{+4000 + 1000}{2} \times 15 = & +37500 \text{ ft. lbs.} \\
\hline
 & +57500 \text{ ft. lbs.} = BJ \\
\dfrac{+1000}{2} \times 5 = & +2500 \text{ ft. lbs.} \\
\hline
 & +60000 \text{ ft. lbs.} = CR \text{ maximum}
\end{array}$$



200 lbs per ft
3000 lbs
4000
5 000
54'-0"
5'-0"
30'-0"
15'-0"
4'-0"
15'-0"
5'-0"
10-0"
4000
K
1000
L
-2000
-5000
X
V
F
V
22500#
80000
57500#
22500#
15000#
20000#
U
B
C
P
D
m
G
Q
M
A
T
H
E
y
O
N
S
J
R
W
Z
X
30000#
50000#
60000#
20000#
200 lbs per ft.
3000
3000
U₁
B₁
V₁
22500
m
A₁
D₁
G₁

Fig. 25

$$
\begin{array}{rl}
\dfrac{-2000}{2} \times 10 = & -10000 \text{ ft. lbs.} \\ \hline
 & +50000 \text{ ft. lbs.} = DW \\
-2000 \times 15 = & -30000 \text{ ft. lbs.} \\ \hline
 & +20000 \text{ ft. lbs.} = EZ \\
-5000 \times 4 = & -20000 \text{ ft. lbs.} \\ \hline
 & 0 \quad \text{at X}
\end{array}
$$

The line OA having the same slope at A as the parabola, is tangent to it; the line DE is likewise tangent to the parabola at D. If the lines OA and ED are produced they will intersect at F, a point directly in line with the center of the uniform load. $OFEX$ would be the moment diagram if the uniform load of 6000 pounds were concentrated at its middle point. The parabola is drawn after the manner described in Fig. 22.

The parabolic segment $ABCDG$ presents some interesting features. Let M represent the bending moment at any section of the beam where uniform load is carried; then the length of any ordinate PS of the moment diagram between $x = 5$ and $x = 35$ is

$$M = 4000x - 200\,(x - 5)\,\frac{(x-5)}{2}$$

$$= -100x^2 + 5000x - 2500 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Let $y = QS$, the ordinate to the line AD, then $\dfrac{QT}{TA} = \dfrac{DH}{HA}$ or

$$\frac{y - 20000}{x - 5} = \frac{50000 - 20000}{30}.$$

Simplifying, $y = 1000x + 15000 \ldots\ldots\ldots\ldots\ldots\ldots (2)$

Subtracting equation 2 from equation 1,

$$M - y = -100x^2 + 4000x - 17500.$$

Let $PQ = m = M - y$ and let $AT = v = x - 5$ or $x = v + 5$.

Then $m = -100\,(v + 5)^2 + 4000\,(v + 5) - 17500$

or $m = 3000v - 100v^2$.

This equation is also the expression for the moment m at a section distant v from the left support of a beam 30 feet long simply supported at the ends and carrying a uniform load of 200 lbs. per foot. Therefore, the lengths of corresponding ordinates in the two parabolic segments $ABDG$ and $A_1B_1D_1G_1$ are equal: the areas of the segments are equal and their centers of gravity are similarly situated.

The slope of the line AD is

$$\frac{DH}{AH} = \frac{30000 \text{ ft. lbs.}}{30 \text{ ft.}} = 1000 \text{ lbs.}$$

The shear ordinate KL is 1000 lbs.; hence the line UV, which is tangent to the parabola at B, has a slope 1000 lbs., and is, therefore, parallel to the line AD. The point B bisects the line FG.

$$BG = BF = B_1G_1 = 22500 \text{ ft. lbs.}$$

The area of the parabolic segment $ABDG$ is ⅔ (area of the rectangle $A_1U_1V_1D_1$) = ⅔ (area of the parallelogram $AUVD$) = ⅔ × 30 ft. × 22500 ft. lbs. = 450000 ft.^{2} lbs.

The value of this principle will be apparent later in the consideration of the static moment of the area of moment diagrams about a vertical axis.

Now I am aware that many of you who have so patiently listened to this explanation relative to areas and centroids are ready to ask why such a method should be given so much attention when the much shorter method of formal symbolic integration by rule and formula will give the desired information in less than half the time. That is, why not solve the problem in this way?

Let ydx equal the limit of the area $PQRS$ (Fig. 23), then the total area OBC is

$$A = \int_0^a y\,dx = \frac{2b}{a}\int_0^a x\,dx - \frac{b}{a^2}\int_0^a x^2\,dx$$

Integrating

$$A = \frac{2b}{a}\left[\frac{x^2}{2}\right]_0^a - \frac{b}{a^2}\left[\frac{x^3}{3}\right]_0^a$$

$$A = \frac{2b}{a}\cdot\frac{a^2}{2} - \frac{b}{a^2}\cdot\frac{a^3}{3} = \frac{2}{3}ab$$

also

$$M = \int_0^a xy\,dx = \frac{2b}{a}\int_0^a x^2\,dx - \frac{b}{a^2}\int_0^a x^3\,dx$$

$$M = \frac{2b}{a}\left[\frac{x^3}{3}\right]_0^a - \frac{b}{a^2}\left[\frac{x^4}{4}\right]_0^a$$

$$M = \frac{2b}{a}\cdot\frac{a^3}{3} - \frac{b}{a^2}\cdot\frac{a^4}{4} = \frac{5}{12}a^2b$$

Again you may ask: In finding the value of x, which will cause y to be a maximum in the equation $y = 2x - 0.2x^2$, why did

you not differentiate by formula and write at once $\dfrac{dy}{dx} = 2 - 0.4x$, which, when equated to zero, gives $x = 5$? Certainly this method of solution is far less laborious than running part way up the hill, then back again, and finally going to the summit and down the other side.

My purpose in going into details with the solutions which have been presented this evening was to rebuild for you a portion of the foundation which was laid during your college days and which possibly has been forgotten and left to decay. I know from experience that the man who spends eight or ten years in practice, working through the grades from draughtsman to chief engineer, does not go back to first principles when the "pocket companion" with its ever-ready formulas and rules is at hand. This rapid transit system usurps the right of way and, riding swiftly onward to a solution, we forget the rock bottom principles which have made our journey possible.

But they still remain the important part of any structure; and this is particularly true in the building of a technical education. The first principles of mathematics should be so clear and so perfectly defined that no one can mistake them. But in many instances quite the opposite is true. There are thousands of teachers (and a few authors) who are still giving the high school student a wrong conception by the use of the infinitesimal analysis, where the idea of the theory of limits should be presented. It is not at all difficult to find a text-book which states that "the circumference of a circle is but an inscribed regular polygon having an infinite number of sides," and thereby demonstrating that the area of a circle is the product of one-half the radius and the circumference.

Now as long as the inscribed figure remains a polygon it is bounded by straight lines, however short they may be; and any legerdemain which attempts to prove to the average boy that a straight line is a curved line, may possibly be accepted, but not without suspicion and reasonable doubt. In this dilemma the young man may stumble along by faith in his teacher, but he certainly does not walk by sight, when the clearness of evidence forsakes him.

How much wiser and better if he were told the truth of the matter, that the perimeter of the polygon with increasing sides approaches the circumference of the circle, but never actually reaches nor exactly equals it. Let radii be drawn in the circle dividing the polygon into triangles. The area of the polygon equals one-half the product of the altitude of a triangle and the perimeter of the polygon. These are the two variables and they are always equal, whatever may be the number of sides or triangles.

By increasing the number of sides of the polygon, its area approaches the constant area of the circle; while the altitude approaches a constant radius, and the perimeter approaches a constant circumference.

The two variables, then, which are always equal, are the area of the polygon, and one-half the product of altitude and perimeter, and they are respectively approaching two constant limits—the area of the circle and half the product of the radius and circumference. Hence the two constant limits are equal or the area of a circle is one-half the product of radius and circumference.

Nor can the engineering profession escape by placing all the blame at the door of the mathematician. In the last decade a number of text-books have appeared under various titles, such as Calculus for Engineers, Mathematics for Engineering Students, etc., written by engineers or engineers in collaboration with mathematicians. Some are very good and others equally poor. In the preface of a book in the latter category we read the following:

> In the calculus a somewhat radical departure has been attempted in order to avoid the difficult and somewhat mystifying theory of limits, or rather to approach similar ends by less technical paths.

This is a quotation from an American book. Now listen to a demonstration on "systematic differentiation" from an English text, written by a mathematician and an engineer:

> When we have a quantity expressed as a graph, we can find its rate of change graphically, although this is a tedious and rather inaccurate process. We now want to see how when we are given the quantity as a formula, we can find the rate of change or differential coefficient in a second formula.
>
> $$y = x^2$$
>
> To obtain the slope $\frac{dy}{dx}$ let us find the change in y when x changes by dx
>
> for x we have $y = x^2$
>
> for $x + dx$ we have $y + dy = (x + dx)^2$
>
> The change in $y = dy =$ new value of y minus old value y
>
> $= (x + dx)^2 - x^2$
>
> $= x^2 + 2x\,dx + dx^2 - x^2$
>
> $= 2x\,dx - dx^2$
>
> Therefore rate of change of y
>
> $=$ change in y divided by change in x
>
> $$= \frac{dy}{dx} = \frac{2x\,dx - dx^2}{dx}$$
>
> $$\frac{dy}{dx} = 2x + dx$$

And then follows this gem:

> When dx is made indefinitely small the second term in the last expression becomes indefinitely small, and passes the limits of accuracy, so that it can be neglected. Hence in the limit
>
> $$\frac{dy}{dx} = 2x$$

A foot note reads as follows:

> Some students find difficulty in following this argument with reference to terms that become so small that they may be neglected. The point to remember is that dx may be as small as we like. Suppose, for instance,

$x = 10$. If we take $dx = \frac{1}{1000}$, $\frac{dy}{dx} = 20 + \frac{1}{1000}$.

If it does not satisfy us to neglect this $\frac{1}{1000}$ take $dx = \frac{1}{1,000,000}$; then $\frac{dy}{dx} = 20 + \frac{1}{1,000,000}$ thus getting smaller and smaller values of dx we have finally $\frac{dy}{dx} = 20$ i.e., $\frac{dy}{dx} = 2x$.

And thus we view the combined efforts of a mathematician and an engineer to steer the student safely around the "mystifying theory of limits." One thing will be perfectly evident to the student concerning the equation $\frac{dy}{dx} = 2x + dx$. If dx is made nothing in the second member of the equation it should be nothing in the denominator of the first member also, in which case we have $\frac{0}{0} = 2x + 0$. We hear now-a-days some discussion about the fourth dimension. I believe it is some sort of a place into which we may throw a right-hand glove and have it return to fit the left hand. Possibly the fifth or sixth dimension may hold a doctrine by which this last equation may be interpreted. But in the light of our present knowledge it "passeth all understanding."

If there be members of my profession who are successful in convincing the student that something equals nothing or that a straight line and a curved line are one and the same thing, I congratulate them rather than their students, but I did not have the temerity to attempt such sophistry in your presence.

I have used the theory of limits because it is the only safe and sane method by which the calculus may be explained to the satisfaction of a logical mind.

References

Philosophy of Mathematics, Bledsoe. 1881. J. B. Lippincott & Co.

Graphical Methods, Runge. 1912. Columbia University Press.

Graphical Calculus, Barker. 1902. Longmans, Green & Co.

Elementary Treatise on Graphs, Gibson. 1905. Macmillan & Co.

HISTORICAL SKETCH OF THE THEORY OF BEAM FLEXURE

During the last thirty years the writers of American and English text-books on mechanics and structures have shown a disinclination to give credit where credit is due by omitting bibliographies. Be-

cause of this fact, it seems fitting to review briefly the historical development of the theory of beams, which is closely interwoven with the more general and theoretical development of the theory of elasticity. A very comprehensive record of the accomplishments in this interesting field is given by Todhunter and Pearson, *History of the Theory of Elasticity and of the Strength of Materials*, Cambridge, 1886. This work has been especially helpful as a reference, and its accuracy has been accepted in those cases where the original contributions could not be obtained.

Galileo Galilei (1564-1642) was the first writer of whom we have any definite knowledge, who attempted to establish the mathematical laws which govern the strength of beams.[1] He assumed that none of the fibers were shortened or lengthened; that every fiber resisted tension, and that this tension was the same for all fibers. His expression for the moment of resistance of a rectangular section was $M = \frac{1}{2} fbh^2$.

Robert Hooke (1635-1702) was probably the first to realize the modern conception of elasticity. In 1678 he published his principle,[2] "*Ut tensio sic vis,*" or "As the extension so is the resistance." This is universally known as *Hooke's Law*. He stated that when a bar was bent, the material of which it was made was compressed on the concave side and stretched on the convex side.

Mariotte (1620-1684) made the following contributions:[3]

1. The material is extended on the convex side and compressed on the concave side:
2. In solid rectangular sections the line of invariable fibres is at one-half the depth of the section.
3. The elongations or compressions increase as their distance from this line.
4. The resistance is the same whether the neutral axis is at the middle of the depth or at any other point.
5. The lever arm of the distance is two-thirds of the depth.

While the last two are erroneous, the first three embody the essential principles as accepted today.

Varignon, in 1702, attempted[4] to reconcile the theories of Galileo and Mariotte by assuming that all the fibres were extended and that the tensile stresses varied uniformly as their distance from the neutral plane, which was at either the top or bottom of the beam.

A. Parent was the first[5] to conceive that for a given normal section of a beam supporting transverse loads, the sum of the

1. *Discorsi e Dimostrazioni matematiche*, Leiden, 1638.
2. *De potentiâ restitutiva*, London, 1678.
3. *Traité du mouvement des eaux*, Paris, 1686, Partie V, Disc. 2.
4. *De la Résistance des Solides . . . en particulier pour les hypothèses de Galilée & de M. Mariotte. Mémoirs de l'Académie*, Paris, 1702.
5. *Des points de rupture des figures. Mémoires de l'Académie*, Paris, 1710.

tensile forces must equal the sum of the compression forces. This fact, when considered with uniform variations of stress, fixes the neutral plane at the center of gravity of the cross section, when transverse forces are considered.

With the study of the strength of beams, consideration was given also to the question of flexure; and in this field three generations of Bernoullis and Leonhard Euler, a pupil of the first generation and an intimate friend of the second, occupy a very prominent place.

James Bernoulli (1654-1705) remarks[6] that he has not much confidence in the calculus invented only recently by Leibntz. He uses its elements only geometrically, i. e., with reference to drawn figures. This appears to be the first suggestion of a semi-graphical application of the calculus. He derived a differential equation of the elastic curve, and it was in his attempt to substitute for it an algebraic expression that he discovered the lemniscate, a curve which resembles the figure eight. His elastic curve is derived for the particular case only where the direction of the load is perpendicular to the curve and corresponds to the third variety of Euler's more general solution.

Leonhard Euler (1707-1783) made his famous contribution[7] in 1744. A quotation from the beginning of his article is of peculiar interest in that it shows the theological and metaphysical point of view common to writers of his day.

> As the plan of the whole universe is the *most* perfect, and as it has been laid down by the *most* wise Creator, nothing happens in this world, that is not based upon some relation of the maximum or the minimum.

As an example, he cites the string-curve, which, at first, had been derived from the effects of gravity; and later on through the method of maxima and minima, when it was recognized that a string must curve in such a way that its center of gravity assume the lowest possible position.

Euler states that his article was suggested by a letter which he received from the "highly esteemed and very sagacious" Mr. Daniel Bernoulli (son of John and nephew of James), in which the latter (Daniel) informed him that the total stress contained in a bent elastic ribbon (very thin rod) may be expressed in the formula of the potential force. The elastic curve may be found by making that expression,

$$\int \frac{ds}{R} \text{ a minimum.}$$

He proceeds to derive his general equation by this method and as a check he also derives it directly.

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6. *Curvatura Laminæ Elasticæ*, printed in the *Acta Eruditorum Lipsiæ*, June, 1694. A German translation by H. Linsenbarth (1910) is found in *Ostwald's Klassiker Der Exakten Wissenschaften*, Number 175. Euler's article is also included. See footnote 7.

7. *De Curvis Elasticis*, 1744.
For German translation, see footnote 6.

His expression for the radius of curvature is $R = \dfrac{(ds)^3}{dxd^2y}$.
He then concludes that the moment is inversely proportional to the radius of curvature without giving any proof whatever. He simply states that the elastic stress (what is now termed the bending moment) is expressed by $\dfrac{Ek^2}{R}$. If we express the moment by M, his equation is $M = \dfrac{Ek^2}{R}$, whence $\dfrac{dxd^2y}{(ds)^3} = \dfrac{M}{Ek^2}$.

Euler finds that the elastic curve has nine different varieties. The third corresponds to Bernoulli's curve, the fifth is the lemniscate, and the last is a circle. He then applies his theory to thin elastic rods or "ribbons" to determine Ek^2, which is his expression for the stiffness of the material. His expression for moment may be written $M = \dfrac{stiffness}{R}$.

We must remember that the expression, *modulus of elasticity*, was of a later date, and that Euler's term E should not in any way be confused with the modern notion of E when used to express the modulus of elasticity. Euler's expression for stiffness was Ek^2, which corresponds to our modern expression EI, but the E of one is not the E of the other.

In his experiments he finds that Ek^2 depends upon the material of which the ribbon is made. Secondly, it depends on the width of the ribbon; so that, other things being equal, the expression Ek^2 is proportional to the width of the ribbon. Thirdly, the thickness plays an important part in the determination of Ek^2. Ek^2 appears to be proportional to the square of the thickness. The expression Ek^2 will contain a term referring to the elastic material; the width of the ribbon in the first power; and the thickness in the second power. Consequently, the elasticities of all materials may be determined and compared with each other by tests, measuring length (breadth is evidently intended) and thickness.

Euler appears partially to have corrected his error as to the square of the thickness in 1778 when in a discussion on columns he finds

$$Ek^2 = h \int x^2ydy$$

where his constant h corresponds to the material, while the integral refers to the dimensions of the member, to which we now refer as the moment of inertia of a cross-section about the neutral plane. His neutral plane, however, appears to be on one face of the column.

Coulomb (1736-1806) deduced his principles[8] from the three

fundamental static equations and generalized the principles of Parent by stating that the algebraic sum of all the forces must be zero on the three rectangular axes. This establishes the position of the neutral axis when the forces are oblique as well as normal.

Coulomb's hypothesis and Hooke's law, together with the assumption that plane sections remain plane after flexure, gives us what some writers have called the "common theory" of beams, as illustrated by the formulas on page 200.

P. S. Girard (1765-1836) published the first *practical* treatise[9] on elasticity. The experiments of his predecessors has been made for the most part upon thin rods. Girard experimented with oak and fir beams, and attempted to make a complete analysis of their elastic properties. Concerning the experiments, he remarks that *cohérence logitudinale* has been neglected in the theory of the resistance of bodies . The long-neglected question of shear has begun to attract attention.

Commenting upon this work, Professor Pearson remarks (Vol. I, p. 77):

> The whole book forms at once a most characteristic picture of the state of mathematical knowledge on the subject of elasticity at the time, and marks the arrival of an epoch when science was to free itself from the tendency to introduce theologico-metaphysical theory in the place of the physical axiom deduced from the results of organized experience.

In attempting to determine the stiffness of a rod by tests, Euler stated that his Ek^2 depended, among other things, upon the nature of the material; that it was different for different substances.

Thomas Young (1773-1829) introduced the term *modulus of elasticity*[10] as a measure of these differences. He defined the modulus as a volume, while the present-day conception is a unit force. Quoting Professor Pearson (Vol. I, p. 82): "Among his (Young's) vast attainments in sciences and languages, that of expressing himself clearly in the ordinary dialect of mathematicians was unfortunately not included." This comment may well apply to Young's definition:

> The modulus of the elasticity of any substance is a column of the same substance, capable of producing a pressure on its base which is to the weight causing a certain degree of compression, as the length of the substance is to the diminution of its length.

Beginning with the year 1800 and following the historical investigations, we find that the increasing number of contributors renders the task of giving due credit for originality more difficult than heretofore.

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8. *Essai sur une application des règles de Maximis et Minimis à quelques Problèmes de Statique, relatifs à l'Architecture*, Paris, 1773.

9. *Traité Analytique de la Résistance des solides, et des solides d'égale Résistance, Auquel on a joint une suite de nouvelles Expériences sur la force, et l'élasticité spécifique des Bois de Chêne et de Sapin*, Paris, 1798.

10. *A course of Lectures on Natural Philosophy and the Mechanical Arts.* Vol. II, 1807. Several of these lectures are found in *Miscellaneous Works of the late Thomas Young* by Peacock, 1855, Vol. II.

The theory of flexure has its greatest practical value when applied to statically indeterminate structures. Several writers[11] state or imply that Navier was the first to apply this principle to continuous beams in 1825; but a letter[12] from Dr. Young to one Mr. Tilloch, written August 3, 1815, is evidence to the contrary:

To Mr. Tilloch.

Sir: The formidable accident, which occurred some time since, from the failure of the hoops of a vat of great size, has led to an inquiry respecting the strength required in structures of this kind; and its results are comprehended in the following propositions. It must be remembered that they are only correctly true upon the supposition that the resisting points are absolutely fixed, and that in actual practice the forces will be somewhat more equally divided; it would, however, be always prudent to make the strength great enough for the most unfavorable supposition that can be made respecting its employment.

A. If a flexible bar, equably loaded throughout its length, be supported at each end and in the middle by fulcrums perfectly fixed, the middle point will sustain ⅝ of the whole pressure.

Let the half length be a, the distance of any point from the middle x, and the pressure on the end y; then the strain at the point, being the joint result of all the forces acting on either side of it, as on the arm of a lever of which it is the fulcrum, will be $y(a-x)-(a-x)\frac{1}{2}(a-x)$, since the weight of the portion $a-x$ acts at the distance $\frac{1}{2}(a-x)$; and the curvature will be as $ay-xy-\frac{1}{2}a^2+ax-\frac{1}{2}x^2$, the curve being supposed to differ but little from a straight line: hence the fluxion of the inclination will be as $ay\dot{x}-yx\dot{x}-\frac{1}{2}a^2\dot{x}+ax\dot{x}-\frac{1}{2}x^2\dot{x}$, the fluent $ayx-\frac{1}{2}yx^2-\frac{1}{2}a^2x+\frac{1}{2}ax^2-\frac{1}{6}x^3$, which requires no correction: and in the same manner the fluent of the ordinate will be found $\frac{1}{2}ayx^2-\frac{1}{6}yx^3-\frac{1}{4}a^2x^2+\frac{1}{6}ax^3-\frac{1}{24}x^4$,

11. Todhunter and Pearson, Vol. I, p. 146.
Mathematical Theory of Elasticity, Love, Second Edition, p. 353.

12. Philosophical Magazine for 1815, Vol. XLVI, p. 139, or *Miscellaneous Works of the late Thomas Young, Peacock,* Vol. II, p. 159.

which must vanish when $x = a$, since the ends are supposed to be absolutely fixed, or $o = \frac{1}{2} a^3 y - \frac{1}{6} a^3 y - \frac{1}{4} a^4 + \frac{1}{6} a^4 - \frac{1}{24} a^4 = \frac{1}{3} y - \frac{1}{8} a$, and $y = \frac{3}{8} a$, which is $\frac{3}{16}$ of $2a$, the whole pressure; so that the two ends support $\frac{3}{8}$ of the whole pressure, and leave $\frac{5}{8}$ for the middle.

The letter continues under five other topics, *B, C, D, E* and *F*, relating to different problems of flexible bars on three supports with special reference to the stave in question. The letter is interesting also because it shows the influence of Newton in the use of the terms "fluxion" and "fluent" and in the dot over the letter in place of the integral sign. Dr. Young's solution may be the better appreciated when re-written in modern terminology. To avoid confusion we shall use V for the end pressure instead of y.

A. If a uniformly loaded beam be simply supported at each end and in the middle by reactions which have no vertical movement, the middle reaction will sustain ⅝ of the total load.

Let the half length be a inches, and the reaction at either end V pounds. Let the load be one pound per lineal inch, then the moment at any normal section x inches from the middle reaction is

$$M = V(a - x) - \frac{1}{2}(a - x)\ (a - x)$$

$$= Va - Vx - \frac{1}{2} a^2 + ax - \frac{1}{2} x^2$$

He assumes that the curvature differs so little from a straight line that, in the expression for the radius of curvature $R = \frac{(ds)^3}{dxd^2y}$, dx may be substituted for ds, and the approximate value

$$R = \frac{dx^2}{d^2y} \quad \text{or} \quad \frac{1}{R} = \frac{d^2y}{dx^2}$$

may be used without appreciable error.

Many modern authors use for the radius of curvature, the expression

$$R = \frac{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{3/2}}{\frac{d^2y}{dx^2}}$$

Since the curvature is slight, $\left(\frac{dy}{dx}\right)^2$ is neglected in comparison with unity, and the expression reduces as before to

$$R = \frac{1}{\frac{d^2y}{dx^2}} \text{ or } \frac{1}{R} = \frac{d^2y}{dx^2}$$

From Euler, Young has

$$M = \frac{\text{stiffness}}{R} \text{ or } \frac{1}{R} = \frac{M}{\text{stiffness}}$$

Therefore $\frac{d^2y}{dx^2} = \frac{M}{\text{stiffness}}$

Hence the curvature $\frac{d^2y}{dx^2}$ will vary as the moment.

$$\frac{d^2y}{dx^2} = \frac{1}{\text{stiffness}} \left(Va - Vx - \frac{1}{2} a^2 + ax - \frac{1}{2} x^2\right)$$

By integrating he has the equation of the inclination of the elastic curve.

$$\frac{dy}{dx} = \frac{1}{\text{stiffness}} \left(Vax - \frac{1}{2} Vx^2 - \frac{1}{2} a^2x + \frac{1}{2} a\,x^2 - \frac{1}{6} x^3 + C_1\right)$$

The elastic curve being symmetrical is horizontal at the center; consequently at the center $\frac{dy}{dx} = 0$, and $x = 0$; therefore, the constant of integration C_1 is zero and, as he says, no correction is required.

Integrating again he has the equation of the elastic curve.

$$y = \frac{1}{\text{stiffness}} \left(\frac{1}{2} Vax^2 - \frac{1}{6} Vx^3 - \frac{1}{4} a^2x^2 + \right.$$

$$\frac{1}{6}ax^3 - \frac{1}{24}x^4 + C_2)$$

Dr. Young has made no reference to the constant of integration in this case. However, the deflection is zero at the center and end, hence $y = 0$ when $x = 0$, also $y = 0$ when $x = a$. The first instance makes $C_2 = 0$, and no "correction" is required.

Making $y = 0$ when $x = a$, gives

$$0 = \frac{1}{\text{stiffness}}\left(\frac{1}{2}Va^3 - \frac{1}{6}Va^3 - \frac{1}{4}a^4 + \frac{1}{6}a^4 - \frac{1}{24}a^4\right)$$

Whence $V = 3/8\, a$.

A laborious study of Dr. Young's writings persuades us to concur in Professor Pearson's comment, and we hope that Mr. Tilloch, otherwise unknown to fame, read the letter with both pleasure and understanding.

E. Claperyon (1799-1864) greatly simplified the problem of continuous beams when uniformly loaded, by establishing a relation between the bending moments at three consecutive supports. This relation is known as "Claperyon's Formula" or the "Theorem of Three Moments." His contribution[13] represents only a summary of his work (done several years previous) which was occasioned by the rebuilding of the bridge of Asnières near Paris, which had been destroyed in 1848. He applies his formula to a proposed bridge over the Garonne at Bordeaux, consisting of seven spans.

Mr. Bender in his "Continuous Bridges," Van Nostrand, on pages 14 and 18, has given Henri Bertot the credit for the discovery of the three moment theorem in 1855. Had Mr. Bender the article to which he refers[14] he would have noted that Bertot gives the credit to Claperyon for the algebraic treatment of the problem, the graphical solution of which is the problem of Bertot.

Bresse[15], Winkler[16] and Weyrauch[17] extended Claperyon's work to include concentrated loads and treated the subject of continuous beams with a completeness and thoroughness which leaves little to be desired.

The theory of elasticity has been developed by two classes of scientists—the mathematical-physicists, in "trying to understand the world," and the engineer in his endeavor to "make it more comfortable." The modern theory in its most general phrase, although initiated and concluded by two men of the latter class—Navier and

13. *Calcul d'une poutre élastique reposant librement sur des appuis inégalement espacés:* Comptes Rendus, des Séances de l'Académie des Sciences, Paris, 1857, vol. 45, p. 1076.

14. *Comptes Rendus de la societe Ingenieurs Civils de Paris,* 1855, p. 278.

15. *Cours de mécanique appliquée,* Paris, 1862.

16. *Die Lehre von der Elasticität und Festigkeit,* Prague, 1867.

17. *Allgemeine Theorie und Bereschnung der kontinuirlichen und enfachen Träger,* Leipzig, 1873.

Saint-Venant, is not applicable, by virtue of its essential refinements, to the technical problems of engineering practice. On the other hand, the only theory by which the strength of a beam could be determined or its deflection calculated was the Bernoulli-Eulerian hypothesis (otherwise known as Coulomb's theory or the "common theory"), which makes the stress and deflection a function of the moment, without regard to the element of shear.

Coulomb had touched upon the question of shear and so had Girard and Young. Poisson and Couchy had included in it their investigations; but their expressions were too intricate to be of practical service.

Such was the situation when Vicat made his protest[18] against the mathematicians in 1833, and insisted upon the importance of shear and impact.

Barré de Saint-Venant (1797-1886) introduced the function of shear[19] into the "common theory" of beams in 1837. His deduction may be stated as follows[20]:

$$f = \frac{M\,y}{I}, \quad v = \frac{S\,Q}{I\,b}$$

$$r = \frac{1}{2} f \pm \sqrt{\frac{1}{4} f^2 + v^2}$$

$$\tan 2\,a = \frac{2v}{f}$$

in which f = unit bending stress in pounds per square inch at distance y from the neutral axis.

M = moment of the external forces at the section in inch pounds.

y = distance in inches from neutral axis to the point.

I = moment of inertia in inches^4 of the cross-section about the neutral axis.

v = longitudinal (or vertical) unit shear in pounds per square inch at the point.

b = width in inches of beam at the point.

V = total shear in pounds at the section.

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18. *Recherches expérimentales sur les phénomènes physiques qui précèdent et accompagnent la rupture ou l'affaissement d'une certaine classe de solides. Annales de ponts et chaussées.* 1883.

19. *Leçons de mécanique appliquée faites par intérim par M. de St. Venant, Ingénieur des ponts et chaussées.*

20. See *Mechanics of Materials*, Merriam, eleventh edition, p. 265.
Strength of Materials, Morley, third edition, p. 22.
Elasticity and Strength of Materials, Burr, 7th edition, p. 163.
Strength of Materials, Boyd, first edition, p. 147.
Structural Mechanics, Greene, 2nd edition, p. 179.

$Q =$ the statical moment in inches^3 about the neutral axis of that portion of the cross section lying on the opposite side of the point from the neutral axis.

$r =$ resultant unit tension and compression on the two principal planes.

$a =$ angle of the stress with the horizontal.

While this expression for finding the maximum tensile or compressive stress at a point in a beam is not exact, it gives a closer approximation than does the "common theory" where the stress is expressed as $f = \dfrac{My}{I}$.

Saint-Venant applies the general equations of elasticity to the problems of flexure of beams in his celebrated memoir[21] nearly twenty years later.

The simplicity of the "common theory" is its greatest advocate. It is sufficiently accurate perhaps for ordinary problems in design, and as an aid to the solution of restrained and continuous beams; but the degree of perfection attained in laboratory apparatus of the present day brings to light its imperfections.

The report[22] of Professor Marburg on a series of Bethlehem beam tests is very convincing on this point.

In his calculations Professor Marburg used the "common theory," thereby giving no consideration to shearing stress or the increase in deflection resulting therefrom. He found from his bending tests that the average modulus of elasticity was 26,300,000 pounds per square inch, whereas the modulus from the tensile tests was 28,700,000 pounds per square inch, "the difference being in general agreement with observations of similar nature by other investigators."

Commenting upon this report, Professor Tilden accounts[23] for the apparent discrepancy by giving due consideration to shear. His solution is very interesting (we can hardly call it "laborious," as Professor Marburg states). To which Professor Marburg replies:

> The element of shear in computing the values of the moduli in bending, was designedly omitted, and that procedure is believed to be justified not only on the ground that it accords with the method commonly followed in practice, but because the apparently greater accuracy of the more refined method is believed to be largely fictitious.

This from an official of the American Society for Testing Materials, in the year of our Lord 1910, is somewhat depressing.

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21. *Mémoire sur la flexion des prismes, sur les glissements transversaux et longitudinaux qui l'accompagnent lorsqu'elle ne s'opère pas uniformément ou en arc de cercle, et sur la forme courbe affectée alors par leurs sections transversales primitivement planes. Journal de Mathématiques de Liouville,* 1856. Extracts to the extent of five pages may be found in the Comptes rendus, 1854.

22. Engineering News, August 12, 1909.

23. Ibid, February 24, 1910.

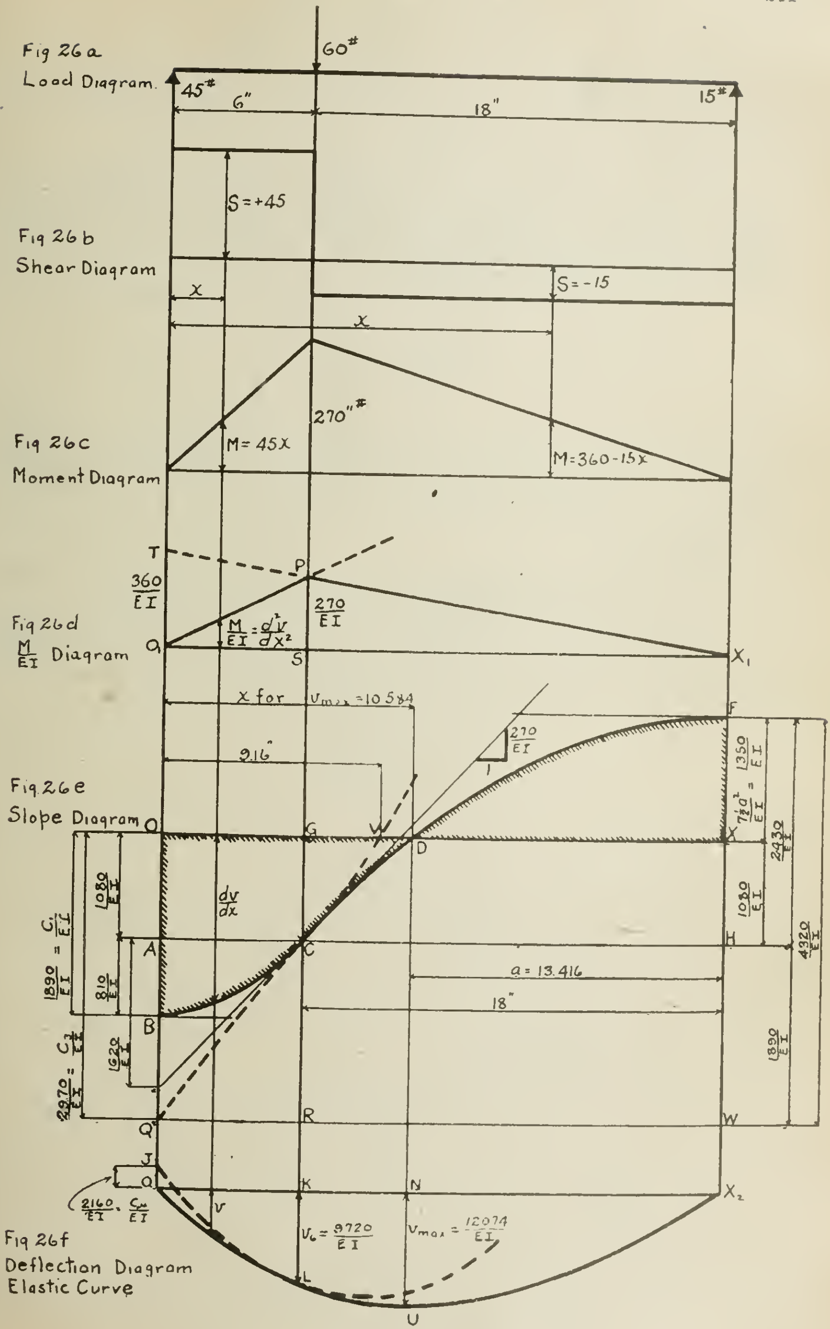


Fig 26a
Load Diagram.
60#
45#
15#
6"
18"
S=+45
Fig 26b
Shear Diagram
S=-15
x
x
270"#
Fig 26c
Moment Diagram
M=45x
M=360-15x
T
P
360/EI
270/EI
Fig 26d
M/EI Diagram
M/EI = d²v/dx²
S
X₁
x for Vmax = 10.584
9.16"
270/EI
1
F
Fig. 26e
Slope Diagram
O
G
W
D
X
1350/EI
1080/EI
C₁/EI = 1890/EI
810/EI
dv/dx
A
C
H
2430/EI
4320/EI
a = 13.416
18"
B
1620/EI
C₁/EI = 2970/EI
1890/EI
Q'
R
W
J
Q
K
N
X₂
2160/EI = C₂/EI
V
V_c = 9720/EI
V_max = 12074/EI
L
U
Fig 26f
Deflection Diagram
Elastic Curve

Fig. 26

Deflections—Elastic Curve.

A knowledge of the relation between the moment diagram and the elastic curve furnishes a method by which statically in determinate problems may be solved.

There are several methods by which this relation may be established and because the best method is, with one or two exceptions, given little or no attention in the standard American texts which treat of *Strength and Resistance of Materials,* we will elaborate somewhat upon this subject.

The second differential equation of the elastic curve is

$$\frac{d^2v}{dx^2} = \frac{M}{EI}$$

At x inches from one end of the beam the bending moment is M inch-pounds and the deflection is v inches. E in pounds per square inch is the modulus of elasticity of the material, and I in inches^4 is the moment of inertia of the cross section about the horizontal centroidal axis.

The beam in Fig. 26a is chosen to illustrate the several methods of finding the *moment* deflection at any point in a beam.

First Method. This was the only method known prior to 1868.

Since the load is eccentric, the elastic curve is unsymmetrical, and equations must be written for each portion of the beam.

Left of Weight.

$$x < 6$$

$$M = 45\,x$$

$$\frac{d^2v}{dx^2} = \frac{1}{EI}\,45\,x$$

$$\frac{dv}{dx} = \frac{1}{EI}\left(45\,\frac{x^2}{2} + C_1\right) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$v = \frac{1}{EI}\left(\frac{45}{2}\,\frac{x^3}{3} + C_1\,x + C_2\right) \ldots\ldots\ldots\ldots (2)$$

$v = 0$, when $x = 0$; $\therefore\ C_2 = 0$

Right of Weight.

$$x > 6$$

$$M = 360 - 15\,x$$

$$\frac{d^2v}{dx^2} = \frac{1}{EI}\,(360 - 15\,x)$$

$$\frac{dv}{dx} = \frac{1}{EI}\left(360x - 15\,\frac{x^2}{2} + C_3\right) \ldots\ldots\ldots\ldots (3)$$

$$v = \frac{1}{EI}\left(360\frac{x^2}{2} - \frac{15}{2}\frac{x^3}{3} + C_3 x + C_4\right) \ldots\ldots (4)$$

$v = 0$, when $x = 24$;

$\therefore 24\,C_3 + C_4 = -69120 \ldots\ldots\ldots\ldots\ldots\ldots (5)$

Equations 1 and 3, representing the slope of the tangent for any point on the elastic curves on either side of the load, must present the same value for the point where the two curves meet under the load for which $x = 6$. Likewise v in equation 2 equals v in equation 4 when $x = 6$.

Equating the values of v in equations 1 and 3 when $x = 6$,

$810 + C_1 = 2160 - 270 + C_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$

Similarly from equations 2 and 4,

$1620 + 6C_1 = 6480 - 540 + 6C_3 + C_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$

Solving equations 5, 6 and 7,

$$C_1 = -1890$$
$$C_3 = -2970$$
$$C_4 = 2160$$

Whence

Left of Weight.

$$\frac{dv}{dx} = \frac{1}{EI}\left(\frac{45}{2}x^2 - 1890\right) \ldots\ldots\ldots\ldots (1a)$$

$$v = \frac{1}{EI}\left(\frac{15}{2}x^3 - 1890x\right) \ldots\ldots\ldots\ldots (2a)$$

And

Right of Weight.

$$\frac{dv}{dx} = \frac{1}{EI}\left(360\,x - \frac{15}{2}x^2 - 2970\right) \ldots\ldots (3a)$$

$$v = \frac{1}{EI}\left(180\,x^2 - \frac{5}{2}x^3 - 2970\,x + 2160\right) \ldots (4a)$$

The deflection under the load may be found by placing $x = 6$ either in equation 2a or 4a.

$$v_6 = \frac{1}{EI}(1620 - 11340) = -\frac{9720}{EI}$$

$$v_6 = \frac{1}{EI}(6480 - 540 - 17820 + 2160) = -\frac{9720}{EI}$$

The deflection v is a maximum where the slope of the tangent to one or the other of the curves is zero.

Placing $\frac{dv}{dx} = 0$ in equation 1a.

$$\frac{45}{2} x^2 = 1890$$

$$x = \pm 9.16 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This result is irrelevant since equation 2a represents the elastic curve *only* for values of x between *o* and 6.

Placing $\frac{dv}{dx} = 0$ in equation 3a.

$$360\,x - 7\tfrac{1}{2}\,x^2 - 2970 = 0$$
$$x = 24 \pm 13.416$$
$$x = 37.416 \text{ or } 10.584$$

Only the second value of x is applicable since equation 4a represents the elastic curve *only* for values of x between 6 and 24.
Placing $x = 10.584$ in equation (4a)

$$v_{\max} = \frac{12074}{EI}$$

Second Method. Possibly a semi-graphic solution will illuminate the algebraic processes of the proceding method.

Fig. 26d represents a $\frac{\text{Moment}}{E\,I}$ diagram, that is, the ordinates M of Fig. 26c have been divided by $E\,I$, hence they represent

$$\frac{M}{E\,I} = \frac{d^2v}{dx^2}$$

One integration gives the "slope" curve (Fig. 26e), the ordinates of which represent $\frac{dv}{dx}$. Integrating the slope curve we obtain the elastic curve (Fig. 26f) the ordinates of which represent the deflection v. Choosing OX as the horizontal axis (Fig. 26e), we will integrate the curve O_1P. In the algebraic solution the constant of integration (C_1 in equation 1) was unknown; likewise in this

1. The figure here shown was drawn to scale *after* the magnitude of OB had been determined, previous to which the figure was nothing more than a rough sketch.

solution we know not where to begin. Apparently there is nothing by which we may determine the magnitude of OB. Looking ahead a bit, we may assume that the elastic curve has a negative slope at the left support, consequently the ordinate[1] OB, which is to measure this slope, is negative.

We will remember that the ordinate OB corresponds to C_1 in the algebraic solution.

Starting at B then, we proceed to integrate the curve O_1P, which has a positive ordinate increasing from zero, by drawing the curve BC horizontal at B with positive slope increasing to $\dfrac{270}{EI}$ at C. P_1 is integrated by drawing CDF having a positive slope $\dfrac{270}{EI}$ at C which decreases until the curve becomes horizontal at F.

As O_1P and PX_1 are two distinct and different lines having nothing in common except that they are inclined straight lines and have a common ordinate PS, so BC and CDF are two different curves having nothing in common except that they are parabolas and have the same slope at C.

Let D be the point where the curve CDF crosses the axis OX, for which $\dfrac{dv}{dx}$ is zero, and let DX equal a.

$BCDF$ is the integral of O_1P_1, hence the difference in the lengths of the two ordinates OB and GC equals the area O_1PS.

$$AB = \frac{270}{EI} \cdot \frac{6}{2} = \frac{810}{EI}$$

Similarly $FH = \text{area } PX_1S = \dfrac{270}{EI} \cdot \dfrac{18}{2} = \dfrac{2430}{EI}$

Remembering that the ordinates of a parabola are respectively proportional to the products of the segments into which each ordinate divides its base line (see page 218), we have

$$\frac{FX}{FH} = \frac{a^2}{18^2} \text{ or } FX = \frac{a^2}{324} \cdot \frac{2430}{EI} = \frac{7\frac{1}{2}a^2}{EI}$$

$$\text{and } XH = FH - FX = \frac{2430 - 7\frac{1}{2}a^2}{EI}$$

We may now sketch the elastic curve by integrating $BCDF$, taking the original position and shape of the neutral axis of the beam as the axis O_2X_2 (Fig. 26f).

O_2UX_2 is the integral of $BCDF$. The difference in the length of the two ordinates at O_2 and X_2 is zero, hence the total shaded area in Fig. 26e equals zero, and we have

$$-\text{area } OBCD + \text{area } DFX = 0$$

$$\begin{aligned} \text{or} \quad & \text{area } OBCD = \text{area } DFX \\ \text{put} \quad & \underline{\text{area } CDXH = \text{area } CDXH} \\ \text{adding,} \quad & \text{area } ABC + \text{area } OXHA = \text{area } CDFH \end{aligned}$$

$$\text{area } ABC = \frac{2}{3} 6 \;.\; AB = \frac{2}{3} \;.\; 6 \;.\; \frac{810}{EI} = \frac{3240}{EI}$$

$$\text{area } OXHA = 24 \;.\; XH = 24 \;.\; \frac{2430 - 7\tfrac{1}{2}a^2}{EI} = \frac{58320 - 180a^2}{EI}$$

$$\text{area } CDFH = \frac{2}{3} \;.\; 18 \;.\; FH = 12 \frac{2430}{EI} = \frac{29160}{EI}$$

$$\text{Therefore } \frac{3240}{EI} + \frac{58320 - 180a^2}{EI} = \frac{29160}{EI}$$

$$\begin{aligned} \text{Whence} \quad a^2 &= 180 \\ a &= 13.416 \end{aligned}$$

$$FX = \frac{7\tfrac{1}{2}a^2}{EI} = \frac{1350}{EI}$$

$$XH = \frac{2430 - 1350}{EI} = \frac{1080}{EI}$$

$$OB = \frac{810 + 1080}{EI} = \frac{1890}{EI}$$

Now that the magnitude of OB has been found, the curve of Fig. 26e may be drawn to scale upon the tangents through B, C and F. It is interesting to note that the distance of B *below* O corresponds to the constant of integration in equation 1.

The maximum deflection NU equals in magnitude either the area $OBCD$ or the area DFX. Equating the deflection to the latter area, we have

$$v_{\max} = \frac{2}{3} \;.\; 13.416 \;.\; \frac{1350}{EI} = \frac{12074}{EI}$$

The deflection KL under the load equals the area $OBCG$.

$$v_6 = \left(\frac{1080}{EI} . 6\right) + \left(\frac{2}{3} . 6 . \frac{810}{EI}\right) = \frac{9720}{EI}$$

Before proceeding with the third method we wish to bring out

clearly the fact that BC and CDF are two different curves; that O_2L and LUX_2 are two different curves; and to co-ordinate more closely these two methods by showing the graphic significance of the algebraic constants of integration.

The curve BC may be continued by integrating the line O_1P produced. The curve will cross the horizontal axis at V where OV equals $+9.16$ corresponding to the positive value of x in equation 5. If CB were produced the curve would be symmetrical about the line OB and would again cut the horizontal axis to the left of O at a distance corresponding to the negative value of x in equation 5.

Now let the curve FDC be continued to intersect the line OB produced at Q. This may be accomplished by integrating the line PT a continuation of X_1P.

$$AQ = CR = \text{area } O_1TPS = \frac{360 + 270}{2EI} \cdot 6 = \frac{1890}{EI}$$

$$OQ = OA + AQ = \frac{1080 + 1890}{EI} = \frac{2970}{EI}$$

The ordinate OQ measured *below* O corresponds to the constant of integration in equation 3.

$QCDF$ is a continuous curve which when integrated gives $JLUX_2$.

$$\cdot\ JO_2 + KL = \text{area } OGCQ.$$

$$FW = \text{area } O_1TX_1 = \frac{360}{EI} \cdot \frac{24}{2} = \frac{4320}{EI}$$

$$\text{area } QCFW = \frac{2}{3} \cdot 24 \cdot \frac{4320}{EI} = \frac{69120}{EI}$$

$$\text{area } CDFH = \frac{29160}{EI} \text{ as before.}$$

$$\text{area } CHWR = \frac{1890}{EI} \cdot 18 = \frac{34020}{EI}$$

$$\text{area } QCR = \frac{69120 - (29160 + 34020)}{EI} = \frac{5940}{EI}$$

$$\text{area } OGRQ = \frac{2970}{EI} \cdot 6 = \frac{17820}{EI}$$

$$\text{area } OGCQ = \frac{17820 - 5940}{EI} = \frac{11880}{EI}$$

$$\therefore JO_2 + KL = \frac{11880}{EI}$$

$$\text{and } JO_2 = \frac{11880 - 9720}{EI} = \frac{2160}{EI}$$

The ordinate JO_2 measured *above* O corresponds to the constant of integration in equation 4.

If the curve O_2L is continued it will have a positive slope beyond the vertical line through V.

The constant of integration for the curve O_2L is zero, corresponding to C_2 in equation (2).

OTHER METHODS

Professor Culmann of the Zurich Polytechnikum was the author of the first treatise on Graphical Statics.[2] This was soon followed in order by English,[3] Italian,[4] and French[5] writers who added little to the originality of the great work of the German author.

Professor DuBois of Yale published the first American treatise on this subject,[6] and although his work was presented more than forty years ago, it has rarely been equaled either in point of accuracy or style.

In 1868 Professor Mohr of the Polytechnikum at Stuttgart made a contribution[7] to the theory of deflections, hereafter referred to as "Mohr's Method."

In 1874 Professor Charles E. Greene of the University of Michigan contributed to the theory of deflections in his "Graphical Method for the Analysis of Bridge Trusses," Van Nostrand.

At about this period many of the leading minds were giving a great deal of attention to the relative merits and costs of single and continuous spans. In his introduction Professor Greene remarks that for continuous trusses and draw bridges "the mathematical investigations are intricate; the formulæ deduced are troublesome in application, and most of the authorities pass over one or both of these problems with a judicious silence."[8] The first two chapters of this work are given to a treatment of single span trusses; the three remaining chapters contain the theory of continuous trusses and draw-spans. It is in the third chapter that we find Professor

2. *Die Graphische Statik.* Culmann, Zürich, 1866.

3. *Reciprocal Figures, Frames and Diagrams of Forces.* Clerk-Maxwell, Transactions of the Royal Society of Edinburgh, 1869-70.

4. *Le figure reciproche nelle statica grafica,* Milan, 1872.

5. *La Statique Graphique et ses Applications,* Paris, 1874.

6. *The Elements of Graphical Statics,* A. Jay DuBois, 1875, John Wiley & Sons.

7. *Beitrag zur Theorie der Holz—und Eisen-konstruktionen; Zeitschrift des Architecten und Ingenieur-Vereins zu Hanover,* Vol. 14, p. 19, 1868. (The John Crerar library of Chicago has a copy.)

Greene's contribution to the theory of deflections, hereafter referred to as "Greene's Method."

This book was superseded in 1879 by "Trusses and Arches, Part II," Wiley & Sons, and we quote the following lines from the preface:

As it is now four years since this method of area moments for the analysis of continuous girders was first given to the public by the author, and as no statement that such a method can be found in any other place has appeared, the author feels warranted in putting forth a claim for priority of discovery and originality. * * * These results have never been obtained, so far as known, in this way before. * * * The author would also ask a candid comparison of his method of Area Moments with the German method.

There has been and still is much controversy over the methods of Mohr (1868) and Greene (1874).

If the two methods are identical the honor certainly goes to Mohr. If they are different there is still an element of doubt in one point as to originality on the part of Professor Greene as will be seen later. The speaker lacks the temerity to attempt a decision of this perplexing and delicate question, and is content simply to set before you the documentary evidence, allowing you to judge the merits of the case for yourselves.

Mohr's Method. The influence of Culmann's "Graphic Statics" (1866) was widespread and started many scientists upon investigation along similar lines. Two years later Professor Mohr's contribution[7] appeared in the journal of the Hanover Society and we quote from the beginning of this work and to some length:

Professor Culmann in his "Graphic Statics" set himself the task to solve by means of projective geometry those problems of the engineering practice which were open to geometrical treatment. The interesting and practicable results contained in that work would have found general application—we feel convinced—had not the learned projective geometry scared away many engineers from their study. We believe that the expedients of the older geometry would have sufficed in many a case, particularly in those most important to the practice. We will justify this view by additional examples at later occasions. In the following elaboration we have tried to treat the theory of the elastic curve graphically. So far, this problem could not be solved even by application of projective geometry.

About this, Mr. Culmann remarks, as follows: "The determination of the reactions of a continuous beam by means of the deflection, whose laws find expression in the theory of the elastic curve, is entirely beyond the Graphic Statics, at least, as far as we command it today. The axiom, usually set out from, is that at every point the radius of curvature of the deflected beam is in inverse proportion of the moment of the exterior forces. But those deflections are so infinitely small and the radii of curvature so infinitely great, that any construction of them is, and will be, impossible, until geometry furnishes us simple relations between the corresponding radii of projective figures, which are situated perspectively, with the point of infinite distance in the vertical line as the center of projection, and with the straight axis of the undeflected beam as a guide-line [Spurlinie]. Then we could distort projectively the deflections of the beam, until the radii of curvature became measureable. As long as we are not in a position to do this, *we have to take to calculation.*"

The above difficulty is eliminiated at once, if the approximation used

8. Professor DuBois made an interesting comment upon this statement in the preface of his *Graphical Statics.*

for the analytical treatment is permitted also for the graphical solution; namely, to introduce for the radius of curvature the approximate value.

$$\frac{1}{\frac{d^2y}{dx^2}}$$

instead of the accurate value

$$\frac{\left(1+\frac{dy^2}{dx^2}\right)^{3/2}}{\frac{d^2y}{dx^2}}$$

For the analytical treatment this approximation is necessary for similar reasons, and, therefore, quite customary. The following considerations serves as an explanation:

In Fig. 27, let $A\ B\ C$ represent a perfectly flexible string whose horizontal pull equals H and let it be loaded with any continuous load of vertical forces. The variable load per unit of length measured along the horizontal axis of abscissae be k. The origin of the co-ordinates is taken at the lowest point of the string. A part $B\ D$ (Fig. 28), between the origin B of the co-ordinates and an arbitrary point D, is cut out of it. In order to restore equilibrium of the forces acting on $B\ D$, the stresses H and S have to be added as external forces at sections B and D respectively.

Let the horizontal component of stress S be H_1 and the vertical component V. Equilibrium requires that
and

$$(1) \quad . \quad . \quad . \quad H = H_1$$

$$(2) \quad . \quad . \quad V = \int_o^x k.\,dx$$

Furthermore, Fig. 28 shows, that

$$(3) \quad . \quad . \quad . \quad \frac{dy}{dx} = \frac{V}{H_1} = \frac{\int_o^x k.\,dx}{H}$$

From this follows through differentiation
or

$$\frac{d^2y}{d\,x} = \frac{k.\,dx}{H}$$

$$(4) \quad . \quad . \quad . \quad \frac{H\,d^2y}{d\,x^2} = k$$

If the above mentioned approximation for the radius of curvature is introduced, the equation of the elastic curve assumes the following well known form:

$$(5) \quad . \quad . \quad . \quad E\frac{d^2y}{dx^2} = \frac{M^*}{T}$$

---

*This relation may be rendered clearer by multiplying each side of equation (5) by the square of the unit of length, for instance by 1 square meter. Then E times 1 square meter becomes a real force and $\frac{M}{T}$ times 1 square meter becomes a real load per unit of length.

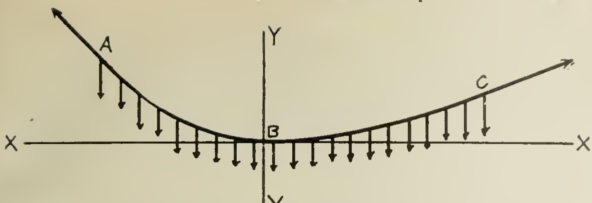


Fig. 27

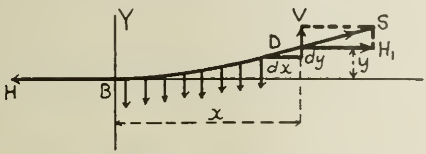


Fig. 28

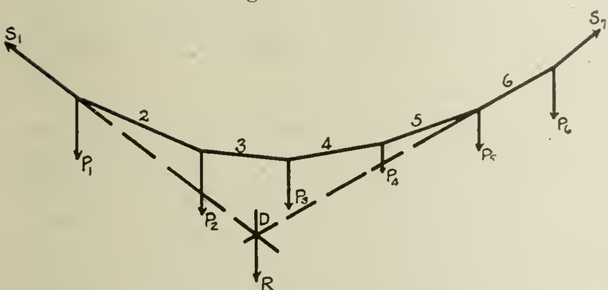


Fig. 29

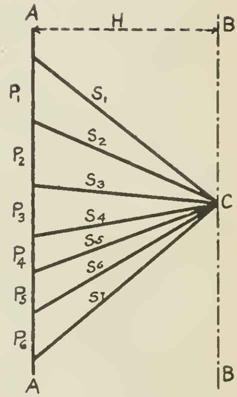


Fig. 30

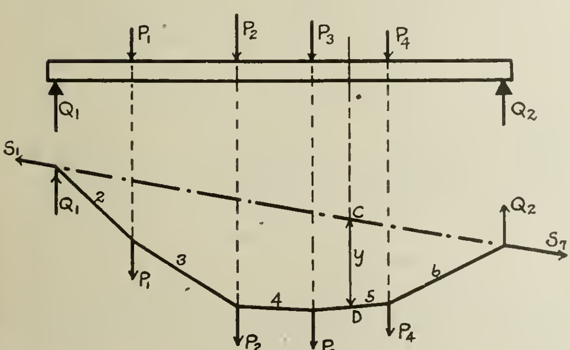


Fig. 31

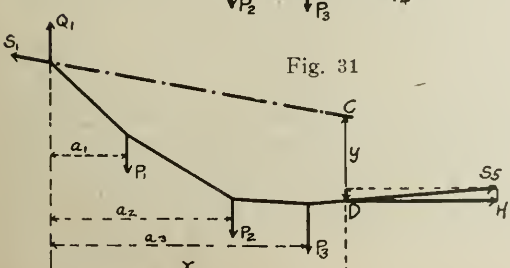


Fig. 32

wherein E is the modulus of elasticity of the material, M the bending moment of the exterior forces and T the moment of intertia of the beam section. Comparison of expressions (4) and (5) shows, *that the elastic curve is a string curve, that the horizontal pull of this string is represented by the constant E, and the vertical load per unit of length of horizontal projection is represented by the variable* $\frac{M}{T}$.

This simple relation not only offers the possibility of solving geometrically all problems that belong here, but simplifies considerably the calculation in many a case.

In order not to be held up by secondary considerations in the following applications, we enumerate here the most important of the properties of the string polygon loaded with vertical loads. They are numbered consecutively with the equations.

A string (Fig. 29) loaded with concentrated vertical forces P_1, P_2, and P_3 . . . . . forms a polygon with the following properties:

(6) Every load, for instance P_3, together with the string stresses S_3 and S_4 of the two adjoining sides of the polygon, form a parallelogram of forces; or, in other words, these three forces joined together according to magnitude and direction form a triangle.

(7) The horizontal components of all string stresses S_1, S_2, S_3 . . . . are equal (equation 1).

(8) By combining the triangles (compare 6), composed of the loads and the string stresses in the two adjoining polygon sides Fig. 30 is obtained, which may be used as an expedient for the construction of the string polygon. Thus, magnitude and direction of the string stresses are obtained by plotting the loads P_1, P_2, P_3 . . . . on a vertical line AA (Fig. 30) in the order of their abscissæ and joining the intersection points to a point C, whose horizontal distance from the vertical line AA equals the horizontal pull H of the string. The position of point C on the vertical line BB may be assumed arbitrarily; but if the direction of *one* string stress is given, the position of point C is determined. Then, to obtain the string polygon, the sides of the polygon (Fig. 29) are drawn parallel to the direction of the string stresses marked with corresponding numbers in auxiliary figure 30.

(9) Any two polygon sides, *e. g.*, S_1, and S_6 (Fig. 29) intersect the resultant R of the loads P_1, P_2, P_3, P_4 and P_5, situated between them, in one and the same point D, because the three forces S_1, R and S_6 are in equilibrium.

(10) If a string polygon is constructed (Fig. 31) for the two reactions Q_1 and Q_2 and the loads P_1, P_2, P_3 and P_4 of a beam supported at two points, the two outermost polygon sides S_1' and S_7 are situated in a straight line. For, the forces Q_1, Q_2 and P_1, P_2, P_3 and P_4 are in equilibrium; outside of these forces only the two stresses S_1 and S_7 act externally on the string. Therefore these two forces must also be in equilibrium; that is, they must act in the same straight line and be of equal magnitude and opposite direction.

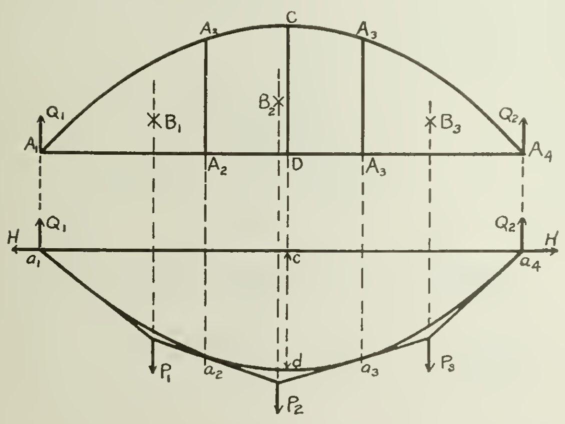
(11) The product $H.\ y$ of the horizontal pull H times the vertical ordinate y of the string polygon (Figs. 31 and 32) to the straight line connecting S_1, S_7, the two outermost polygon sides, equals the bending moment acting in vertical section $C\ D$ of the beam represented in Fig. 31.

Items 12 and 13 give a proof of the statement that $M = H\ .\ y$. Professor Mohr continues:

(14) From this relation follows, what the form of equation (4) clearly indicates, namely, if two string polygons are constructed for the same vertical forces but with two different horizontal pulls H_1 and H_2, the corresponding vertical ordinates of these two polygons in reference to any polygon side are to each other in inverse ratio of the two horizontal pulls. This property makes possible the application of the graphical method to the theory of the elastic curve. The horizontal pull E of the string curve formed by the

elastic curve is extremely great in comparison with the loads $\frac{M}{T}$ in nearly all practical cases. Therefore, if the loads and the horizontal pull were plotted in the *same* scale, the ordinates of the curve would turn out extremely small, (compare Fig. 30). On account of above property of string polygons and string curves, however, the horizontal pull and the loads may be plotted in *two different* scales. The only thing one has to do to obtain the actual values of the ordinates, is to reduce in the ratio of those two scales the vertical ordinates in reference to a tangent or a chord of the curve. If it is a case of scaling the amount of deflection from the drawing, the most serviceable way is, as a rule, to choose the ratio of the scale for the horizontal pull E to the scale for the loads $\frac{M}{T}$ exactly the same as the ratio of the abscissæ in the drawing to the actual length of the abscissæ. For instance, if the abscissæ are drawn in the ratio 1:300, plot the loads $\frac{M}{T}$ in a scale 300 times that for the horizontal pull E. In consequence, the ordinates of the string polygon will appear magnified 300 times, their proper ratio to the abscissæ; and the deflections on the drawing are obtained in *their natural size.*

In item 15 Professor Mohr shows a beam loaded with three loads, P_1, P_2, and P_3 to which a fourth load, P_4, is added, and proves that the increases in deflection of the beam due to the newly added



Figs. 33, 34

load equals the deflection which the weightless beam would assume at the point under consideration, if acted upon by that load alone.

(16) Fig. 33 represents the loading of a string in such a manner, that the load per unit of length of the horizontal axis of abscissae be measured at any point by the ordinate of the curve A_1, A_2, A_3, A_4. The area A_1, A_2, A_3, A_4, called the loading area, is divided into arbitrary parts by ordinates A_2A_2, A_3A_3, and in the centers of gravity of these parts, vertical forces P_1, P_2, P_3 are placed, whose magnitude corresponds with the area of the respective parts. A string polygon a_1 a_2 a_3 a_4 (Fig. 34) constructed with those forces, and with a horizontal pull H, will be tangent to the string curve for the loading represented in Fig. 33, in the verticals through points A_1,

A_2, A_3 and A_4. Because in these points, the moment equations as well as the vertical components of the string stresses are identical for string polygon and string curve. Hence any number of points on the string curve may be determined by adequate division of the loading area. Q_1 and Q_2 are the reactions of the loading area on the two supports A_1 and A_4, and the ordinate $C\ D$ divides the loading area so that

$$A_1\ C\ D = Q_1$$

and

$$A_4\ C\ D = Q_2$$

Then the longest ordinate $c\ d$ of the string curve will be in the vertical of ordinate $C\ D$, because at point d the string curve is parallel to line $a_1\ a_4$ connecting the two points of supports.

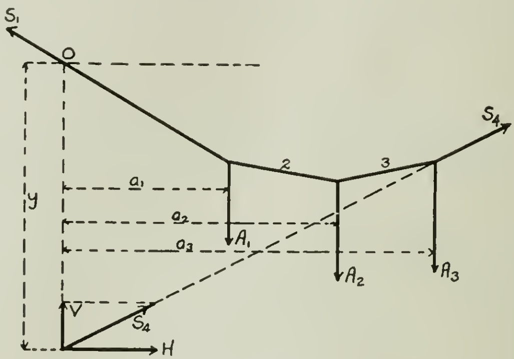


Fig. 35

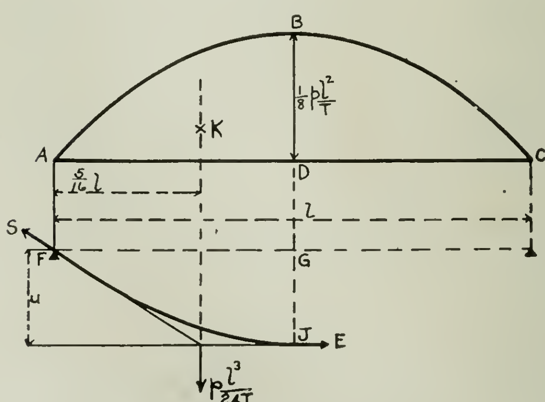


Fig. 36

(17) In order to construct the elastic curve for a beam with variable cross section, one may make a graphical representation of its $\frac{M}{T}$, divide this loading area into parts by ordinates, consider each part as a single load and draw a string polygon with a constant horizontal pull E. In most cases, however, it is simpler to plot the variable quantity $E\ T$ as horizontal

pull in the auxiliary figure which shows the relative inclination of the polygon sides and to consider the graphical representation of M as loading area of the string curve. From equation (5) follows immediately, that this method must needs lead to the same result. It may be given the following form

$$E\ T \frac{d^2y}{dx^2} = M$$

so that comparing with expression (4), the quantity $E\ T$ appears as horizontal pull. The explanations to problem (3), given further down, will show this even clearer.

(18) The string polygon can be used to determine graphically the value of algebraic expressions in the form of a sum of moments

$$a_1.A_1 + a_2.A_2 + a_3.A_3 \quad . \quad . \quad . \quad .$$

If a string polygon is constructed for the vertical loads A_1, A_2, A_3 . . . . acting on the string at the abscissae a_1, a_2, a_3 . . . . , then the distance y to the intersection of the last polygon side with the ordinate axis is the measure of that sum; because the moment equation of the string polygon, (Fig. 35), in reference to the origin O of the co-ordinates, is

$$H.y = a_1.A_1 + a_2.A_2 + a_3.A_3$$

In order to facilitate the multiplication of H and y, H is naturally chosen a round figure in such cases.

Calculation and Graphical Determination of the Deflection of Loaded Beams.

In determining deflections, only the abscissa and the ordinate at the *greatest* deflection between two points of support are wanted, as a rule, while the remaining part of the bending curve is of no interest for the purpose of the problem. This problem is solved by finding the ordinate (compare 16) which divides the loading area of the elastic curve in two parts equal to the reactions of the supports. This ordinate intersects the elastic curve at the point where the deflection is greatest. The tangent at this point is parallel to a straight line connecting the two points of support. In the moment equation for the point of support, expressing equilibrium of the elastic curve to the left or the right of the point of greatest deflection, this deflection is the only unknown quantity. The graphical method outlined under No. 17 is preferable only, if the above determination of the abscissa of the greatest deflection becomes too complicated on account of an irregular shape of the loading area.

Problem 1. Deflection of a simple beam of constant cross section, supported at ends, loaded uniformly with p per unit of length.

The loading area representing $\frac{M}{T}$ is a parabola $A\ B\ C$ (Fig. 36) with its apex above the middle of the beam. The ordinate there is

$$B\ D = \frac{p\ l^2}{8\ T}$$

The greatest deflection occurs at this point on account of the symmetry of the loading area. The following forces act on the left half $F\ J$ of the elastic curve.

(1) at point J, the horizontal string stress E, equal to the modulus of elasticity.
(2) at point of support F, the string stress S, and
(3) the loading equal to the area.

$$A\ B\ D = \frac{2}{3} . \frac{l}{2} . \frac{pl^2}{8T} = \frac{pl^3}{24T}$$

The horizontal distance of the center of gravity K of this area from support F equals $^5/_{16}\, l$. Hence, the moment equation in reference to point F is:

$$0 = E \,.\, u - \frac{pl^3}{24T} \,.\, \frac{5}{16} l$$

or

$$u = \frac{5}{384} \frac{pl^4}{ET}$$

Problem 2. Deflection of a simple beam of constant cross section, supported at ends, carrying a concentrated load "Q" at a distance "a" from the middle.

In this case the loading area is a triangle $A\ B\ C$ (Fig. 37) whose altitude at the loaded point D is

$$B\ D = \frac{Q\,(l^2 - 4\,a^2)}{4\,lT}$$

The action of the loading area on support A is found from the moment equation about point C

$$Vl = \frac{Q\,(l^2 - 4a^2)\,.\,l}{4\,lT} \,.\, \frac{}{2} \,.\, \left(\frac{l}{2} - \frac{a}{3}\right)$$

$$V = \frac{Q\,(l^2 - 4a^2)\quad(3l - 2a)}{48\,lT}$$

The loading area between support A and an ordinate $F\ G$ in the distance.

$$A\ G = b$$

is
$$A\ F\ G = \frac{b}{2} \,.\, \frac{Q(l^2 - 4a^2)}{4lT} \,.\, \frac{b}{\frac{l+a}{2}} = \frac{Q(l-2a)b^2}{4lT}$$

This area equale the above value of V, if

$$b = \sqrt{\frac{(l+2a)\,(3l-2a)}{12}}$$

Hence, the moment equation about point M of part $M\,J$ of the elastic curve reads

$$0 = E.u - \frac{Q(l-2a)b^2}{4lT} \,.\, \frac{2}{3} b$$

or, substituting above value of b,

$$u = \frac{Q(l-2a)}{144l\,ET} \sqrt{\frac{(l+2a)^3\,(3l-2a)^3}{3}}$$

For a concentrated load at the *middle* of the beam becomes

$$a = 0$$
$$b = 1/2l$$

and

$$u = \frac{Ql^3}{48ET}$$

Professor Mohr's article continues with a somewhat lengthy discussion of continuous girders comprising two or three times the amount of material here given with many figures. We believe that sufficient data has been given for a fair estimate of the character of this work.

The figures here shown are identical with those in the original

contribution, except that the numbering has been changed so as to conform to the sequence of this article.

Greene's Method. The following is Professor Greene's method as set forth in Chapter III of his "Graphical Method for the Analysis of Bridge Trusses," beginning with article 20 on page 30:

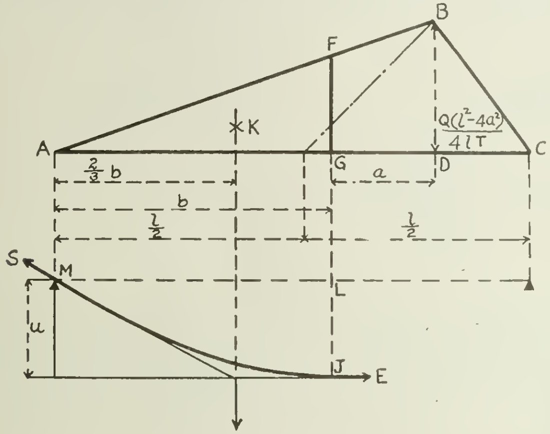


Fig. 37

20. Let us pass next to the case of a beam supported at two points, loaded at intervals, and overhanging one of the points of support. Let *A I*, Fig. (38), be the beam, supported at *A* and *B*, and let the weight of the beam be considered as concentrated with the additional loads. Draw the stress diagram *012*, as in other cases. Commence at *A'*, and draw *A'C'D'E'F'G'I'* parallel to the radiating lines of the stress diagram, the angles occurring on the verticals let fall from the *weights*. There will be one line, parallel to *o-2*, still to be added, and this line should be drawn from *I'* to the vertical through *B*. Connect *A'B'* and the moment diagram is complete. A line through *O*, parallel to *A'B'*, will divide the load line into the two supporting forces, P_1 at *A* and P_2 at *B*.

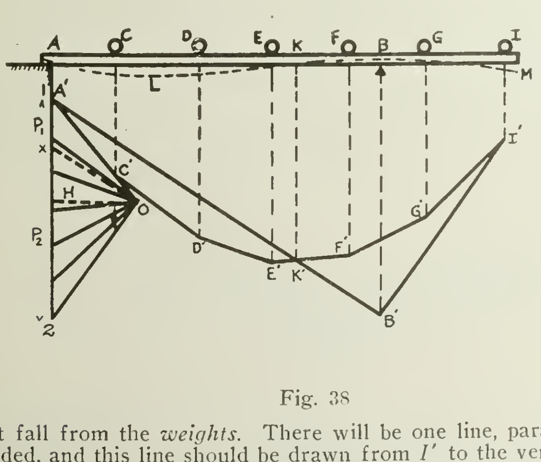


Fig. 38

Drawing the horizontal line marked H through O, we find the bending moment at any point by multiplying H by the ordinate between the moment curve and the line $A'B'$ or $B'I'$ for that point. At K', there being no ordinate, the product is zero; consequently the beam is not bent at K. As we pass from K' to B' and I', the ordinate, being below the curve, may be called negative; the bending moment is in the contrary direction over the portion $K\ I$, from that existing over $A\ K$, and it tends to produce convexity on the upper side of the beam, reversing the tension and compression on the fibres.

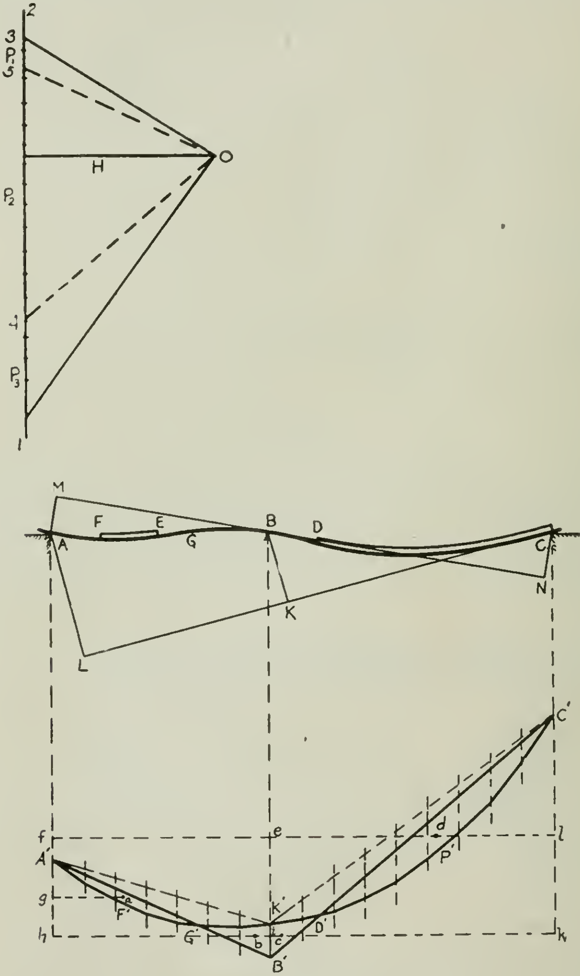


Fig. 39

The point K is called a *point of contra-flexure*. The curvature of the beam is shown, to an exaggerated scale, by the dotted line $A\ L\ B\ M$.

In case the beam overhangs both points of support we may have two points of contra-flexure; but the overhanging portions may have sufficient weight to cause convexity upwards over all the intermediate portion, when

the line corresponding to $A'B'$ will pass entirely below the curve and there will be no points of contra-flexure. If the two points of support are brought together into one point, and the two overhanging portions balance each other, we have the case of a pivot or swing bridge when open.

(21). If we next turn our attention to a girder continuous over two spans, the simplest case of which is a beam resting on three supports, we

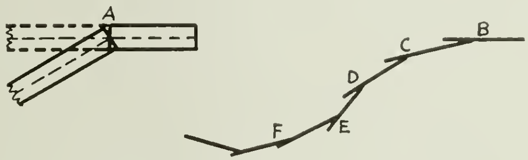


Fig. 40

shall find that a partial solution of the problem by mathematical calculation is attended with considerable difficulty, and that a complete solution for the bending moment and shearing force at every section, under moving, partial and irregular loads, taxes the powers of the best mathematicians and is well nigh impossible, on account of the complexity of the formulae, so far as

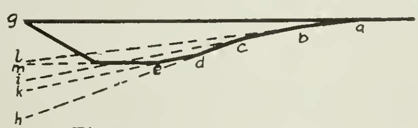


Fig. 41

any practical application of them by the engineer is concerned. Where each span has a uniform load over its whole extent, although different spans may have loads of the same or different intensities, Clapeyron's "Formula of the Three Moments" will readily give us the moments over the piers for a continuous girder, and hence we can obtain the moments at other points; and, if the beams are symmetrically loaded, or so loaded as to be horizontal over the piers, the investigations are not difficult and can be found in most text-books treating of the flexure of beams. But no book in

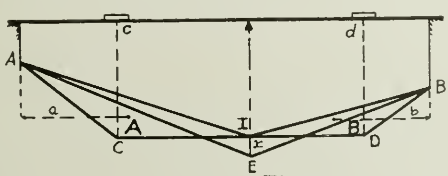


Fig. 42

common use gives us any method for determining the shearing stress under a partial load, a determination which is necessary before the bracing can be correctly proportioned.

We propose now to develop a graphical method which will be readily applicable to all cases of continuous girders, under discontinuous and moving loads, and by which we can as easily determine the maxima stresses on the

chords and bracing of any truss, loaded in any manner, as we have done for single spans in the preceding pages. The diagrams will show, what might have been expected from analogy, that the maxima stresses on the chords of continuous girders occur when one or more spans are fully loaded, and the maximum stress on a brace occurs when the moving load covers one of the segments into which the piece under consideration divides the span; but, in both cases, the stresses in one span are very materially altered by the presenec or absence of a load on the adjacent spans.

(22). Suppose that we have a beam, as represented in Fig. 39, supported on two abutments, A and C, and divided by the pier at B into two unequal spans. Its own weight is uniformly distributed, and it carries, in addition, a uniformly distributed load of twice the intensity from C to D and also from E to F. Divide the two spans into convenient parts, equal or unequal (here taken equal), and consider the load to be concentrated at the points of division. Draw verticals through these points, and, having constructed the load line and stress diagram 012, draw the moment curve between C' and A', as in previous examples. The loads at A and C are neglected, and are represented by the portions of the load line which project at 1 and 2; since B carries a load, the vertical through B will determine one of the angles of the moment line, in the same way as any other loaded point.

To complete the construction we must draw $A'B'$ and $C'B'$. We know that B' must lie below the curve (for we have a negative moment of flexure over B), and we usually have two points of contra-flexure, where $A'B'$ and $C'B'$ cut the curve. We must have, further, some condition to limit the position of B', since there is manifestly but one correct value for the moment of flexure over the pier for a given position of the load. As no bending moment exists at A, A' B' must start from A ; and, similarly, C' B' is drawn through C'.

(23). From the bending moment there arises in the beam a change of inclination at successive points, and a deflection, either positive or negative, of all portions of the beam from the original horizontal line. For the bending moment at any point, being opposed by the moment of resistance of the beam, causes an elongation and compression of the fibres on opposite sides of the beam, proportional to the bending moment. This elongation and compression causes (see Fig. 40) a change of direction of the centre line of the beam, in a vertical plane, at that point. Therefore the change of direction of inclination at any point is proportional to the bending moment at that point, or to the ordinate between the moment curve and the straight line, (as $A'B'$, Fig. 39), and the total change of inclination between any two points is proportional to the sum of all the bending moments between those points, or to the area included between the *moment curve,* the straight line from the abutment to the pier and the two limiting ordinates under the points.

By reference to Fig. 40, we can see the change of inclination produced in the beam at A, by the elongation of the upper fibres at that point and the compression of the lower ones. We can also see the effect of successive changes of inclination, at B, C and D, in altering the direction of the beam, and we must note that the changes of inclination at E, F, etc., produced by bending moments in the opposite *direction,* tend to bring the beam back towards its original direction. Consequently, the change of inclination between any two points is proportional to the *algebraic* sum of all the ordinates to the moment curve between those points; and, in Fig. 39, supposing $C'B'$ and $B'A'$ to be correctly placed, if we cut off an area from G' towards B', equal to the area between A' and G', the centre line of the beam, at the point vertically over the dividing ordinate just drawn, will have its tangent parallel to the tangent at A. If we know any point where the beam is horizontal, we can thus find the other points where it is horizontal; but the determination of this question is not material to our problem.

(24.) The *deflection* of any point of a beam from the original line depends upon the changes of inclination and the distances of the points at which they occur from the first point. Thus, if the originally straight

stick $a\ g$, Fig. 41, is bent at a, the point g will be carried to a point on the line $a\ e$, the distance through which it is displaced depending upon the angle at a and the distance $a\ g$; if another angle is made at b, the point g will now be found on $b\ i$, and, on a further bending at c, it will move to the direction $c\ h$. The changes of inclination at d, e and f, in the contrary direction, will carry the point which was originally at g, through $d\ k$, $e\ m$, $f\ g$, finally back again to g. (The deflections of all beams and trusses are so small that the curved line of a beam under a load is always considered practically equal in length to the horizontal distance between the two points of support.)

We see, then, that the position of a point D, Fig. 39, in a beam under flexure, in reference to some point, such as C, as origin, and from a tangent to the beam through that origin, depends upon the successive changes of inclination between the two points and the distances from the point D at which they occur, regard being paid to the direction of the change of inclination. Then, as each change of inclination is proportional to the ordinate to the moment curve, the deflection of a point from a tangent through the origin is proportional to the sum of the products of each ordinate into its distance from the point in question; or, as the horizontal distances are the proportional projections of the distances on the tangent, and as the sum of each ordinate multiplied by its horizontal distance from D is the same thing as the area between C' and D' multiplied by the distance of its centre of gravity horizontally from D', *the deflection of D from the tangent through C is proportional to the area $C'D'$ multiplied by the horizontal distance of its centre of gravity from the vertical through D.* Then, if $C\ L$ is the tangent through C, the deflections of the points B and A, with reference to C, will be proportional to $B\ K$ and $A\ L$, or, from the similarity of triangles, to $B\ C$ and $A\ C$, two known quantities.

(25) Therefore the two lines $A'B'$ and $C'B'$ must be drawn to a point B', so situated that (denoting the centres of gravity of the respective areas by a, b, c and d), the areas

$$\frac{C'P'D'\ .\ d\,e - K'D'B'\ .\ c\,i}{C'P'D'\ .\ d\,f - K'D'B'\ .\ ch - K'B'G'\ .\ bh + A'F'G'\ .\ a\,g} = \frac{B\,C}{A\,C}$$

All of these quantities are readily measured and computed, as will soon be shown; therefore we may draw $A'B'$ and $C'B'$ as trial lines, as near the right position as we can, and then compute the first ratio. If it does not equal the second ratio, move B' and try again; a second approximation will generally be sufficient. Call any area, as above, multiplied by its distance from a certain point, an *area moment.*

We may, with advantage, modify a little the application of our method, and so obtain a rule more easily remembered and used. Draw the tangent $M\ B\ N$ to the beam at B. It is evident that $N\ C : M\ A = B\ C : B\ A$. Then, from the preceding reasoning, make

$$\frac{area\ C'P'D'\ .\ dl - K'D'B'\ .\ ck}{area\ K'B'G'\ .\ bh - A'F'G'\ .\ ag} = \frac{B\ C}{B\ A}$$

The deflection $M\ A$ being on the opposite side of the tangent from $N\ C$, the similar areas in the above proportion are taken with the opposite signs; that is, $K'D'B'$ being taken minus in the first term, $K'B'G'$ is taken plus in the second, and so of the others. Or we may consider the distances to the right of B plus, and those to the left minus.

It is evident that there is but one position of B' which will satisfy the condition; for, if B' is carried still further below K', the first term of the proportion is diminished and the second term is increased, while, if B' is raised, the reverse takes place.

(26) Another demonstration of the above theorem, which is brief and which may be more satisfactory to some mathematical minds, is as follows:

Let M denote the bending moment at any point of a beam, supported in any way; let E denote the modulus of elasticity of the material and I the

moment of inertia of the cross-section. Let the originally straight horizontal line of the beam be the axis of x, and let y be measured vertically. M will be a function of x. Let r = radius of curvature at any point. Then we may write the well-known equation for the curvature

$$\frac{l}{r} = \frac{d^2y}{d\,x^2} = \frac{M}{E\,I}$$

If we integrate this expression once, considering I constant, we have

$$\frac{dy}{dx} = \frac{1}{E\,I}\int M\,d\,x = \text{tan. inclin.} = \text{inclination when small.}$$

If we could determine the constant of integration, we could find the inclination of the beam to the horizon at each point. But, if we integrate from o to x, the origin being taken at one of the points of support, say C, Fig. 39, we get a complete integral,—the area included between the moment curve and the straight line,—but one expressing only the change of inclination from the inclination already existing at C, or the inclination of the tangent at any point to the line $C\ L$.

Integrating again, we have

$$y = \frac{l}{E\,I}\int\int M\,d\,x^2 = \textit{deflection.}$$

This integral is a volume, and, taken between limits as before, is the summation of each area from o to x, into a height dx, giving a cone with a base $= \int_o^x M\,dx$ and a height x; or it is otherwise equal to the area. $\int M\,dx$ multiplied by the distance of its centre of gravity from the point whose abscissa is x. I is here considered constant, and may be so taken in most trusses. If I varies, it will be expressed in terms of x and introduced within the integral sign.

(27) The areas are readily measured by scaling the successive ordinates and multiplying by the constant distance between two ordinates, as is done in calculating the contents of any irregular area by offsets. If the verticals are not too far apart, the areas are practically parabolic segments, triangles, and combinations of the two. The centre of gravity of a parabolic segment, such as $C'D'P'$, is at d, half way horizontally between C' and D'. The centre of gravity of any triangle whose base is vertical, is on a vertical line one-third of the horizontal distance from the base to the vertex. If we connect G' and K' by a straight line, the area $G'K'B'$ will be found to be the difference between a triangle and a parabolic segment, and the moments of these areas about $A'h$ may be computed separately. Similarly, if an area is partly bounded by portions of two different parabolas, the common point of the two parabolas may be connected with the extreme points of the area, and it will thus be divided into a triangle and two parabolic segments. It may be unnecessary to remark that any area may be divided into a number of parts, the respective centres of gravity found, and then the area moments of these parts calculated and combined, with the same result as if the area had been treated as a whole.

(28) If the two spans are equal the *ratio* of the *area moments* becomes an *equality*.

When we have finally determined the position of $A'B'$ and $C'B'$ for

the given load and distribution of the same, we have, as in single spans, the bending moment at each point by taking the proper ordinate and multiplying by H from the stress diagram. Now, upon drawing from 0 two lines, 04 and 05, parallel to $B'C'$ and $A'B'$, we shall divide the load line into three portions which are: 1-4 the supporting force at C, 4-5 the supporting force at B, and 5-2 the supporting force at A. The beam, as now loaded, has two points of contra-flexure, at D and G. It may happen that, when one of the spans is much longer and more heavily loaded than the other, the point of contra-flexure, G', on the shorter span, moving towards the outer end, may finally pass off altogether. As G' moves towards A', the point 5 will approach 3, and, when G' reaches A' and disappears, 5 will pass beyond 3. There will still be some slight pressure on the abutment, although the span $A\ B$ will be convex upward throughout its whole extent; and the end of the beam will not rise from the abutment A until it is found necessary, in order to satisfy the conditions of proportionality of *area moments,* to so draw $A'B'$ that its parallel, 0-5, passes entirely outside of the end 2 of the load line. As soon as this occurs, the beam must be treated as one resting on two supports and overhanging at one end, sec. 20, Fig. 38.

. . . .

(29). Before proceeding farther we will show that it is possible, without extra work, to determine the position of B' and eliminate approximations. We will illustrate by a simple example; the proof made use of can be extended to any case. Let a beam of two spans, c and d, Fig. 42, have a single load on each span. The moment curve will be similar to $A\ C\ D\ B$, the one represented. Let us suppose, for an instant, that there is no bending moment over the pier. Then drawing $A\ I$ and $I\ B$ we should complete our figure, and calling the area of the triangle $A\ C\ I = \mathbf{A}$, of $I\ D\ B = \mathbf{B}$, and the distances of the centres of gravity of these triangles, from the verticals through A and B, respectively a and b, we ought to have the proportion $\dfrac{-\mathbf{A}\,a}{\mathbf{B}\,b} = \dfrac{c}{d}$. Since a bending moment over the pier does exist, this equation will not be true. Then change the lines $A\ I$ and $I\ B$ to $A\ E$ and $E\ B$, moving on the vertical a distance $I\ E = x$.

We now have the area moments on one side proportioned to the area moments on the other, as c to d. But the area moments on the left are equivalent to

$$\mathbf{A}\,a - A\,I\,E\,.\,\frac{2}{3}c,$$

$\dfrac{2}{3}c$ being the distance of the centre of gravity of $A\ I\ E$ from the abutment vertical. Also the area of $A\ I\ E$ is $\dfrac{cx}{2}$. A similar relation exists on the right. Therefore we may state our proportion as follows:

$$\frac{-\mathbf{A}\,a + \dfrac{c\,x}{2}\,.\,\dfrac{2}{3}c}{\mathbf{B}\,d - \dfrac{d\,x}{2}\,.\,\dfrac{2}{3}d} = \frac{c}{d}.$$

Everything here being known except x, we obtain the distance which B' (Fig. 39) should be below K', when c and d denote the spans, A and B the areas $A'F'K'$ and $K'P'C'$, and a and b the lever arms of their respective centers of gravity,

$$x = \frac{3(\mathrm{A}\,ad + \mathrm{B}\,bc)}{cd(c+d)} = \frac{3}{c+d}\left(\frac{\mathrm{A}\,a}{c} + \frac{\mathrm{B}\,b}{d}\right)$$

If $c = d$ $$x = \frac{3}{2c^2}\left(\mathrm{A}\,a + \mathrm{B}\,b\right)$$

Thus we can readily determine the position of B', and thence the rest of the construction follows simply.

There is no failure when the beam happens to be horizontal over the pier B, for then $M\,A$ and $N\,C$ are each zero, and therefore area $C'P'D' \,.\, d\,l$ = area $K'B'D' \,.\, c\,k$, or $K'B'G' \,.\, b\,h = A'F'G' \,.\, a\,g$.

If great accuracy is not required, and, in any case, after a little practice, one can determine the positions of the centres of gravity, and hence the area moments, without dividing the areas into simpler portions.

The curves of the two spans might be constructed separately, as we should do for detached spans; but, in this case, we must have the same

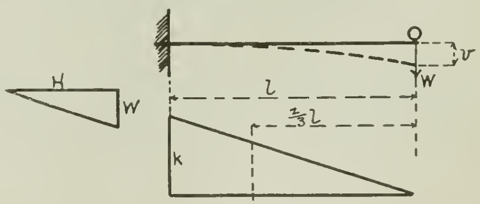


Fig. 43

value of H for both curves, and they must coincide on the vertical through the center pier. Therefore, in drawing the curves, we could start from K', or any other point on the centre vertical, and work each way. Indeed, the curves might cross the horizontal line through C', and can be transferred, at any time, if desired, to that line, by measuring off ordinates, either above or below it, so that $A'\ B'$ and $B'\ C'$ shall coincide with or become the horizontal line. Most authors who show any moment curves for girders draw them in this way. The construction of the curve for each girder by a separate stress diagram will be shown presently, in an example of four continuous spans.

Professor Greene closes this chapter with a practical application of his method to a truss of two unequal continuous spans. Continuous girders of many spans and the draw or pivot span are treated in chapters IV and V. The material in this book consisting of seventy-nine pages was thoroughly revised, enlarged and published in Part II of Trusses and Arches, four years later in 1879, as before stated.

In Chapter VI of this later work we find also the essentials of Professor Greene's "Method by Area Moments," to which he has added several applications to the deflections of simple beams; and

for the sake of comparison we will consider the first, fifth and sixth applications, the last two of which are respectively similar to problems 1 and 2 of Professor Mohr's method.

91. 1st, Beam fixed at one End, loaded at the Other.—The beam built into a wall or otherwise fixed at one end, and carrying a weight W at the free end, will take the form of the dotted curve sketched in Fig. 43. If W

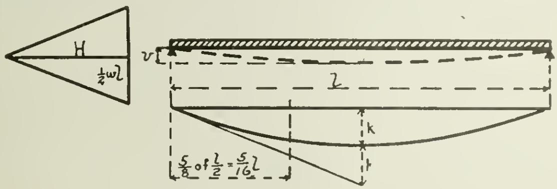


Fig. 44

is laid off on a vertical line, it will represent the load and also the shear at any point of the beam from this load. Drawing H from one end, and completing the stress diagram, we see that the equilibrium polygon is a right-angled triangle, the bending moment increasing simply as the distance

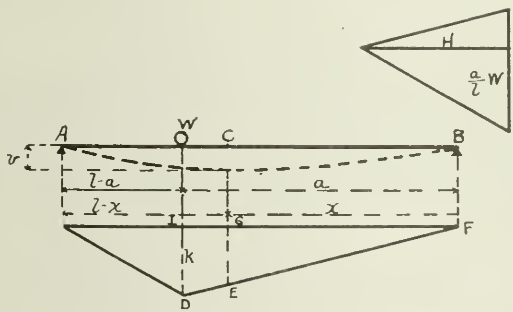


Fig. 45

from the free end of the beam. Let k denote the height of this triangle. Then, by proportion, we shall have

$$W \ : H = k \ : l; \text{ or } H\,k = W\,l = M \text{ (max)}.$$

The area of the triangle $= k \ . \ \frac{1}{2} l$. If the beam is of uniform cross-section, I is constant. We have, then, for the slope at the extreme end, where the weight is attached,

$$tan.\,i = \sum_0^l \frac{H}{E\,I} y = \frac{H}{E\,I} \sum_0^l y = \frac{1}{E\,I} H\,k . \frac{1}{2} l = \frac{W\,l^2}{2\,E\,I}$$

The centre of gravity of the triangle being distant $\frac{2}{3} l$ from the apex horizontally, the deflection will be obtained by multiplying *tan.* i by this distance, or

$$v = \frac{W\,l^2}{2\,E\,I} \cdot \frac{2}{3}\,l = \frac{W\,l^3}{3\,E\,I}$$

which is the vertical distance that the point of attachment of the weight is below the tangent at the fixed end.

95. *5th, Beam supported at Both Ends, and uniformly loaded with $w\,l$.*—The equilibrium curve, Fig 44, will be the well-known parabola. The tangent at one end will cut the middle ordinate prolonged at $2\,k$ from the horizontal line: hence

$$\frac{1}{2}\,w\,l : H = 2\,k : \frac{1}{2}\,l;\ \text{or}\ H\,k = \frac{1}{8}\,w\,l^2 = M\ (\text{max.}),$$

as has previously been shown. Then from the parabolic area, we get

$$tan.\,i = \frac{1}{E\,I} \cdot \frac{1}{8}\,w\,l^2 \cdot \frac{2}{3} \cdot \frac{1}{2}\,l = \frac{w\,l^3}{24\,E\,I}$$

The centre of gravity of the semi-segment of the parabola is $\frac{5}{8}$ of $\frac{1}{2}\,l$ from the abutment; hence

$$v = \frac{w\,l^3}{24\,E\,I} \cdot \frac{5}{16}\,l = \frac{5}{384}\,\frac{w\,l^4}{E\,I}$$

96. *6th, Beam supported at Both Ends, carrying a Single Weight, distant a from the Right.*—This case is represented by Fig. 45, and is given as a sample of the flexibility of the method. a is greater than $1/2\,l$. The reaction at the left point of support will be $\frac{W\,a}{l}$. Then by proportion, as usual,

$$\frac{W\,a}{l} : H = k : l - a;\ \text{or}\ H\,k = \frac{W\,a(l-a)}{l} = M\ (\text{max.}).$$

The point where the beam is horizontal is at present unknown; but at that point, which will not be at the weight, is manifestly the maximum deflection. Suppose that the point is C, distant x from B. The distance which C is below A will be equal to $\frac{H}{E\,I}$ multiplied by the area moment of the area in the equilibrium polygon to the *left* of the dotted line below C. The area moment to the *right* of the dotted line multiplied by the same quantity will be the deflection of C below B. As the tangent at C is horizontal, these two expressions must be equal: hence to find the point of maximum deflection resolves itself into so dividing the equilibrium polygon by a vertical line, that the area moment on one side, about the abutment on that side, shall equal the similar moment on the other side about its abutment. The quantity $\frac{H}{E\,I}$, being constant, will not affect x.

The dotted line will cut off a trapezoid from the triangle to the right of the weight. One of its parallel sides being k, the other will be given by the proportion

$$a : k = x : \frac{k\,x}{a},$$

and its area will be equal to one-half the sum of its two parallel sides multiplied by $a - x$, the perpendicular distance between them: hence the area of the trapezoid is

$$\frac{1}{2}\left(k+\frac{k\,x}{a}\right)\left(a-x\right)=\frac{1}{2}k\frac{a^2-x^2}{a}.$$

By taking moments about F for the triangle $F\ D\ I$, we see that $D\ I\ F\ .\ \frac{2}{3}\ a - E\ G\ F\ .\ \frac{2}{3}\ x = D\ I\ G\ E$ multiplied by x', the distance of centre of gravity from F, or in symbols,

$$\frac{k\,a}{2}\ .\ \frac{2}{3}a-\frac{x}{2}\ .\ \frac{k\,x}{a}\ .\ \frac{2}{3}x=\frac{1}{2}k\ .\ \frac{a^2-x^2}{a}\ .\ x';$$

$$\frac{1}{3}k\frac{a^3-x^3}{a}=\frac{1}{2}k\frac{a^2-x^2}{a}\ .\ x', \text{ or}$$

$$x'=\frac{2}{3}\frac{a^3-x^3}{a^2-x^2};$$

and the distance of the centre of gravity of the trapezoid from $A = l - x'$: hence, making the area moment of the small triangle plus the trapezoid about A equal to the moment of the remaining area about B, we have

$$\frac{1}{2}k\left(l-a\right)\ .\ \frac{2}{3}\left(l-a\right)+\frac{1}{2}k\frac{a^2-x^2}{a}\left(l-\frac{2}{3}\frac{a^3-x^3}{a^2-x^2}\right)$$

$$=\frac{1}{2}\frac{kx^2}{a}\ .\ \frac{2}{3}x\quad (b).$$

Dropping common factors, we get

$$(l-a)^2+\frac{a^2-x^2}{a}\left(\frac{3}{2}l-\frac{a^3-x^3}{a^2-x^2}\right)=\frac{x^3}{a}$$

$$a(l-a)^2+\frac{3}{2}l(a^2-x^2)-a^3+x^3=x^3$$

$$\frac{3}{2}lx^2=al^2-\frac{1}{2}a^2l$$

$$x=\sqrt{\frac{1}{3}a\ (2l-a)}.$$

Substituting this value of x in the second member of the deflection equation (b) from which it was deduced, we see that

$$v=\frac{H}{EI}\cdot\frac{1}{3}\frac{kx^3}{a}=\frac{Wa(l-a)}{lkEI}\cdot\frac{1}{3}\frac{k}{a}\cdot\frac{1}{3}a(2l-a)\sqrt{\frac{1}{3}a(2l-a)}$$

$$=\frac{W(l-a)\ a(2l-a)}{9EIl}\sqrt{\frac{1}{3}a(2l-a)}\,;$$

which expression, when $a=\frac{1}{2}l$, reduces to $\frac{Wl^3}{48EI}$.

The slope at B will be

$$tan.\,i=\frac{H}{EI}\cdot\frac{kx}{a}\cdot\frac{1}{2}x=\frac{W(l-a)a}{6EIl}\,(2l-a).$$

The slope at A will be obtained similarly.

It is hoped that the documentary evidence concerning the Mohr-Greene controversy here presented will provoke some productive criticism relative to the points in question.

No discussion of this question would be conclusive without a further consideration of paragraph 26 of Professor Greene's text, quoted above, wherein he states that the integral expression $\int M\,dx^2$ is the volume of a cone.

Professor Greene was appointed to the Chair of Civil Engineering at the University of Michigan in 1871, succeeding Professor DeVolson Wood, who had been called to the Stevens Institute of Technology.

In the same year Professor Wood's "Treatise on the Resistance of Materials" was published by Wiley & Son, and was used by Prof. Greene as a text the year following.*

Flexure is the subject of Chapter V, comprising forty-five pages. The first thirty-five pages present the ordinary algebraic treatment, which is followed by a graphical method from which we quote, section 108, page 129:

108. The Graphical Method consists in representing quantities by geometrical magnitudes, and reasoning upon them, with or without the aid of algebraic symbols. This method has some advantages over purely analytical processes; for by it many problems which involve the spirit of the Differential and Integral Calculus may be solved without a knowledge of the processes used in those branches of mathematics; and in some of the more elementary problems, in which the spirit of the Calculus is not involved, the quantities may be directly presented to the eye, and hence the solutions may be more easily retained. It is distinguished, in this connection, from pure geometry by being applied to problems which involve mechanical principles, and to use it profitably in such cases requires a knowledge of the elementary principles of mechanics as well as of geometry.

But graphical methods are generally special, and often require peculiar treatment and much skill in their management. It is not so powerful a mode of analysis as the analytical one, and those who have sufficient knowledge of mathematics to use the latter will rarely resort to the former, unless it be to illustrate a principle or demonstrate a problem for those

*See Catalog University of Michigan, 1872.

who cannot use the higher mathematics. A few examples will now be given to illustrate the method.

109. General Problem of the Deflection of Beams.—*To find the total deflection of a prismatic beam which is bent by a force acting normal to the axis of the beam* without the aid of the Calculus.

Let a beam, AB, Fig. 46, be bent by a force, P, in which case the fibres on the convex side will be elongated, and those on the concave side will be compressed. Let AB be the neutral axis. Take two sections normal to the neutral axis at L and N, which are *indefinitely near each other*. These, if prolonged, will meet at some point as O. Draw KN parallel to LO. Then will ke, $= \lambda$, be the distance between KN and EN at k, and is the elongation of the fibre at k. Let $eN = y$, then from the similar triangles kNe and LON we have

$$ON : Ne :: LN : ke = \lambda = \frac{Ne \,.\, LN}{ON} = \frac{LN}{ON} y.$$

If, now, we conceive that a force p, acting in the direction of the fibres, or, which is the same thing, acting parallel to the axis of the beam, is applied at k to elongate a single fibre, we have,

$$p = E \,.\, \Delta a \frac{ke}{LN} = \frac{E}{ON} y \,.\, \Delta a.$$

in which Δa is the transverse section of the fibre and E the modulus of elasticity. As the section turns about N on the neutral axis, the amount of this force is

$$py = \frac{E}{ON} y^2 \Delta a,$$

which is found by multiplying the force by the perpendicular y.

This is the moment of a force which is sufficient to elongate or compress any fibre whose original length was LN, an amount equal to the distance between the planes KN and EN measured on the fibre or fibre prolonged. Hence, the sum of all the moments of the resisting forces is

$$\Sigma py = \frac{E}{ON} \Sigma y^2 \Delta a.$$

in which Σ denotes summation; and in the first member means that the sum of the moments of all the forces which elongate and compress the fibres is to be taken; and in the second member it means that the sum of all the quantities $y^2 \Delta a$ included in the transverse section is to be taken. The quantity, $\Sigma y^2 \Delta a$ is called the *moment of inertia*, which call I.

But the sum of the moments of resisting forces equals the sum of the moments of the applied forces. Calling the latter ΣPX, in which X is the arm of the force P, and we have

$$\Sigma py = \Sigma PX = \frac{E}{ON} \Sigma y^2 \Delta a = \frac{E.I}{ON}$$

$$\therefore ON = \frac{E.I}{\Sigma PX} \quad \ldots\ldots\ldots\ldots (139)$$

In the figure draw Lb tangent to the neutral axis at L, and Na tangent at N. The distance ab, intercepted by those tangents on the vertical through A, is the deflection at A due to the curvature between L and N. As LN

is indefinitely short, it may be considered a strainght line, and equal x; and $Lb = LC$ very nearly for small deflections; and $LC = X$. (L stands for two points.)

By the triangles OLN and aLb, considered similar, we have

$$ON : x :: Lb : ab = \frac{Xx}{ON}$$

in which substitute ON from equation (139) and we have

$$ab = \frac{Xx \Sigma PX}{E.I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (140)$$

which is sufficiently exact for small deflections. If, now, tangents be drawn

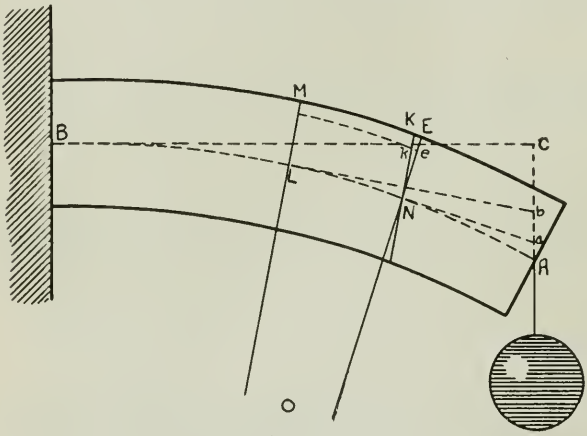


Fig. 46

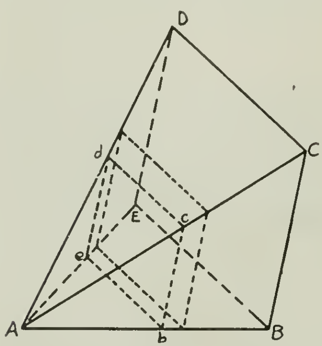


Fig. 47

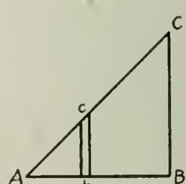


Fig. 48

at every point of the curve AB, they will divide the line AC into an infinite number of small parts, the sum of which will equal the line AC, the total deflection. But the expression for the value of each of these small spaces will be of the same form as that given above for ab, in which P, E, and I are constant.

This is as far as we can proceed with the general solution. We will now consider

PARTICULAR CASES

110. Case 1. Let the Beam be Fixed at One End, Fig 46, and a Load, P, be applied at the Free End. The moment of P, in reference to any point on the axis, is PX. Hence ΣPX is simply PX, which, substituted in equation (140), gives

$$ab = \frac{P}{E.I} X^2 x$$

$$\therefore AC = \frac{P}{E.I} \Sigma X^2 x \quad \ldots\ldots\ldots\ldots\ldots\ldots (141)$$

This equation has been deduced directly from the figure. It now remains to find the sum of all the values of X^2x, which result from giving X all possible values from $X = o$ to $X = l$*. To do this, construct a figure some property of which represents the expression, but which has not necessarily any relation to the problem which is being solved. If X be used as a linear quantity, X^2 may be an area and X^2x will be a small volume. These conditions are represented by a pyramid, Fig. 47, in which $AB = l =$ the altitude, and the base $BCDE$ is a square, whose sides, BC and CD, each $= l$. Let $bcde$ be a section parallel to the base, and make another section infinitely near it, and call the distance between the two sections x.

*This by the calculus becomes $\int_o^l x^2\,d\,x = \frac{1}{3} l^3$.

Then $AB = X = bc = cd$,

$X^2 =$ area $bcde$, and
$X^2x =$ the volume of the lamina $bcde$.

which is the expression sought. The sum of all the laminae of the pyramid which are parallel to the base is limited by the volume of the pyramid, and this equals the value of the expression ΣX^2x between the limits o and l. The volume of the pyramid is the area of the base $(=l^2)$ multiplied by one-third the altitude $(\frac{1}{3}l)$, or $\frac{1}{3}l^3$, which is the value sought,

$$\text{Hence, } AC = \frac{Pl^3}{3E.I}$$

The value of X^2x may also be found by statistical moments as follows: Let ABC, Fig. 48, be a triangle, whose thickness is unity, and which is acted upon by gravity (or any other system of parallel forces which is the same on each unit of the body). Take an infinitely thin strip, bc, perpendicular to the base, and let

$AB = l = BC$,
$Ab = X = bc$, and
$p =$ the weight of a unit of volume.

Then $Xx =$ the area of the infinitely thin strip bc, and
$pXx =$ the weight of the strip bc, and
$pX^2x =$ the moment of the strip, when A is taken as the origin of

moments. If the weight of a unit of volume be taken as a unit, the moment becomes X^2x, which is the quantity sought, and the value of ΣX^2x from o to l is the moment of the whole triangle ABC. Its area is $\frac{1}{2}l^2$, and its centre of gravity $\frac{2}{3}l$ to the right of A. Hence the moment is $\frac{1}{3}l^3$ as before found*.

Professor Wood then applies this method to several other simple and more common cases, and concludes as follows:

114. Remark about Other Cases.—This method, which appears so simple in these cases, unfortunately becomes very complex in many other cases, and in some it is quite powerless.

As an illustration of the latter case he cites the case of a beam fixed at both ends and uniformly loaded. In his dilemma Professor Wood failed to apprehend that which no doubt appeared quite obvious to Professor Greene, when he used the book as a text, viz., that Professor Wood's pyramid was nothing more nor less than the statical moment of the area of the moment diagram about a certain axis.

In the preface Professor Wood states that his book contains the substance of his lectures to the Senior Class in Civil Engineering, in the University, during the past few years, on the Resistance of Materials.

This book (published in 1871) antedates Greene's contribution by three years. If we knew whether the graphical method as set forth in his book was presented by Professor Wood to his classes prior to Mohr's contribution in 1868, our judicial horizon on this question would recede considerably.

*This may be written $\sum_{x=o}^{x=l} X^2x = \frac{1}{3}l^3$

An excellent presentation of the graphical or semi-graphical method is found, a monograph* on "Deflection of Beams" written by A. E. Greene (son of Charles E.) when he was Professor of Civil Engineering at the University of Michigan.

Since this document is still in print we will make no quotation therefrom, but will content ourselves with presenting for your comparison with other methods, herein set forth, a solution of the problem heretofore considered by the method outlined in the monograph.

Our problem is to determine v_6 the deflection under the load and v_{max} the maximum deflection for the beam as shown in Fig. 49. We note that this is the same problem as shown in Fig. 26.

Let $O\ A\ B\ C$ represent the elastic curve grossly exaggerated and $P\ Q\ S$ the moment diagram. The ordinate $Q\ V$ is 270 inch

*Reprint from The Michigan Technic, June, 1910, Ann Arbor, Mich.

pounds. Draw the line $F\ G$ tangent to the elastic curve under the load at A. The tangent $H\ L$, drawn through B the point of maximum deflection is horizontal. Of course, the original position of the beam was $O\ E\ C$, but we can well imagine that its original unstrained position might have been $F\ A\ G$ and that the moments

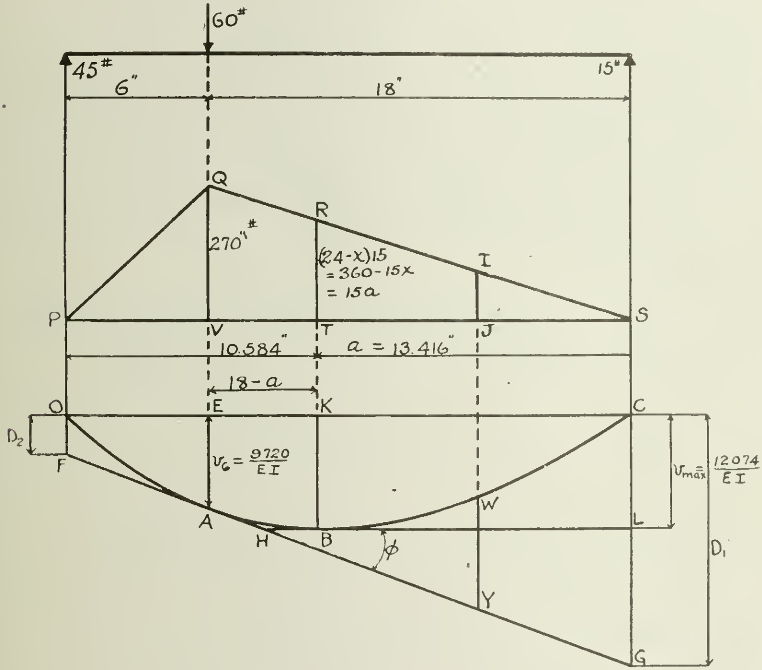


Fig. 49

were afterwards applied to the beam which bent it from the position $F\ A\ G$ into the final position $O\ A\ B\ C$. The distance between the tangent and the elastic curve measured on any vertical ordinate as $W\ Y$, $O\ F$ or $C\ G$ is called the tangential deviation.

There are two principles to remember for beams of constant cross section.

1. The angle between *any* two tangents to the elastic curve equals $\frac{1}{E\,I}$ times the area of the moment diagram between ordinates through the points of tangency. Or the angle $L\ H\ G$ is

$$\phi = \frac{\text{area } Q\ R\ T\ V}{E\ I} \text{ (circular measure)}$$

2. Choose *any* two points on the elastic curve as A and W, and draw a tangent through A. Then the tangential deviation $W\ Y$ equals $\frac{1}{E\ I}$ times the area of the moment diagram between ordinates through A and W, times the horizontal distance from the center of gravity of the area to the ordinate through W. Or

$$W\ Y = \frac{1}{E\ I} \text{ times the static moment of the area } Q\ I\ J\ V \text{ about}$$

$I\ J$. This is often expressed as $\frac{1}{E\ I}$ times the area-moment of $Q\ I\ J\ V$ about $I\ J$.

$$D_1 = \frac{1}{E\ I} \text{ times area-moment of } Q\ S\ V \text{ about } S.$$

$$D_1 = \frac{1}{E\ I}(270 \times 9 \times 12) = \frac{29160}{E\ I}$$

$$D_2 = \frac{1}{E\ I} \text{ times area-moment of } P\ Q\ V \text{ about } P.$$

$$D_2 = \frac{\text{E I}}{1}(270 \times 3 \times 4) = \frac{3240}{\text{E I}}$$

$$D_2 - D_1 = \frac{25920}{E\ I}$$

$$v_0 = D_1 + \frac{D_2 - D_1}{4} = \frac{9720}{E\ I}$$

The slope of the line $F\ G$ is

$$\phi = \frac{D_2 - D_1}{24} = \frac{1080}{E\ I} = \frac{\text{area } Q\ R\ T\ V}{E\ I}$$

Let $T\ S = a$, then $V\ T = 18 - a$, $R\ T = 15a$

$$\text{Area } Q\ R\ T\ V = \frac{270 + 15a}{2}(18 - a) = 1080$$

$a^2 = 180$
$a = 13.416$
$R\,T = 15\,a = 201.24$

$$v_{max} = C\,L = \frac{1}{E\,I}\,\frac{201.24 \times 13.416}{2}\cdot\frac{2}{3}\,13.416 = \frac{12074}{E\,I}$$

Here we have a method giving the same results as obtained by the first and second methods and in much less time. The difference in labor is even more marked in any but the simplest problems. This method* is particularly applicable to the solution of unknown moments in restrained and continuous beams. It is very difficult to understand why this method has not been more widely adopted, for it certainly "deserves a much more extended use than it enjoys at present."

*See Greene's *Monograph*.
Church's *Mechanics of Engineering*, 1908, p. 485.
Deflections of Beams, Ellis, Engineering Record, January 15, 1916.

PITTING OF WATER TURBINES AND THEIR DESIGN.

By S. J. Zowski*

Presented February 5, 1917

One of the most disagreeable things in water turbine practice is the pitting of some of the important turbine parts. It is, therefore, natural to ask whether the designer has any control over this phenomenon, that is to say, whether by proper design he can eliminate or at least reduce it to a minimum. As this question obviously interests not only the turbine designers, but also the turbine users it is proposed to discuss it in this paper.

Whatever theory or theories we may advance to explain the phenomenon of pitting as such—and the electrolytic theory of corrosion seems to cover the case very well, pitting being nothing else but localized and intensified corrosion — one thing is absolutely certain: namely, that the most important part in this phenomenon is played by the oxygen which is present in the water in solution.

Water is a great absorber of gases. We shall, therefore, always find different gases in it—some chemically bound, others in solution. Water as used in water turbines will always have a certain amount of air which it absorbs from the atmosphere. The amount of each gas absorbed by the water is in direct proportion to its s. c. partial pressure, that is to say, that pressure which it will exert if it fills the volume occupied by the mixture quite alone.

Since in atmospheric air there are about 79 volume parts of nitrogen and 21 volume parts of oxygen, their partial pressures are in the ratio of 79:21. Since further, according to Bunsen, the coefficient of absorption or solubility for oxygen is 0.04115 at 0° centigrade and 760 mm. mercury and that for nitrogen is 0.020346, the coefficient of absorption for air at the same temperature and barometric pressure will be

$$0.21 \times 0.04115 + 0.79 \times 0.020346 = 0.008642 + 0.016073 = 0.024715.$$

That is to say, in each 1,000 cubic feet of water there will be 24.715 cubic feet of air in solution at 0° centigrade and 760 mm. barometric pressure. In this air there will be 8.642 cubic feet of oxygen and 16.073 cubic feet of nitrogen. Percentually the amount of oxygen will be $8.642 \div 24.715 = 34.97$ per cent.

Thus the air absorbed by water is richer in oxygen than that of the atmosphere.

The presence of the other gases in the atmosphere and also the temperature will modify these values somewhat. With increasing temperature, as is well known, the water cannot hold as much of the absorbed gases as it can at the lower temperatures. Accord-

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ing to Henry's law the amount of gases which may be held by the water in solution varies directly as the pressure to which the water and gases are exposed—or in other words, the volume of gas or gases which water can hold in solution is constant and definitely fixed for each gas.

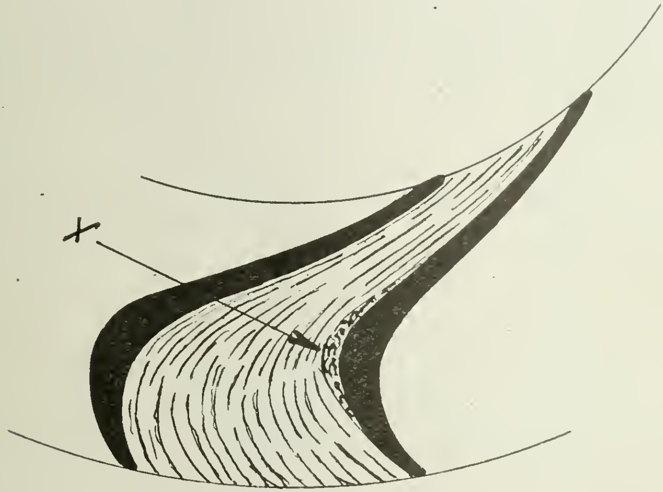

Fig. I

This is important in our case, for it is clear that, when the pressure in the water falls below that of the atmosphere, a certain part of the absorbed air will liberate itself. If, for instance, the pressure in the water falls to one-half of an atmosphere (vacuum

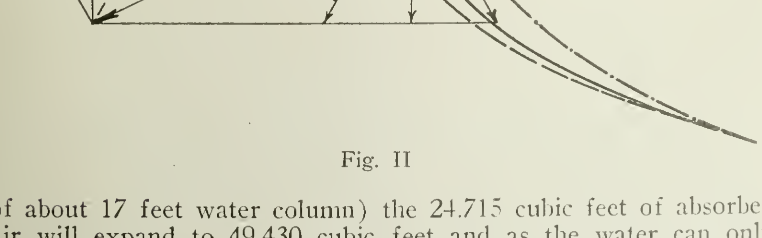

Fig. II

of about 17 feet water column) the 24.715 cubic feet of absorbed air will expand to 49.430 cubic feet and as the water can only hold 24.715 cubic feet—one-half of the air will liberate itself.

Where this deaeration takes place bodily in the stream, that is to say, at no particular points there it will do no special harm

(ordinary corrosion will, of course, take place), but if this deaeration takes place at certain and always the same points, or if the liberated air comes in contact with the metal at certain and always the same spots, pitting will set in, and the destructive action will be the more intense, the more oxygen is liberated.

In water turbine runners, having buckets shaped as shown in Fig. 1 the curvature at point X is usually too sharp for the water streams to follow. The stream line will rebound and what might properly be termed "cavitation" will occur, that is to say, a

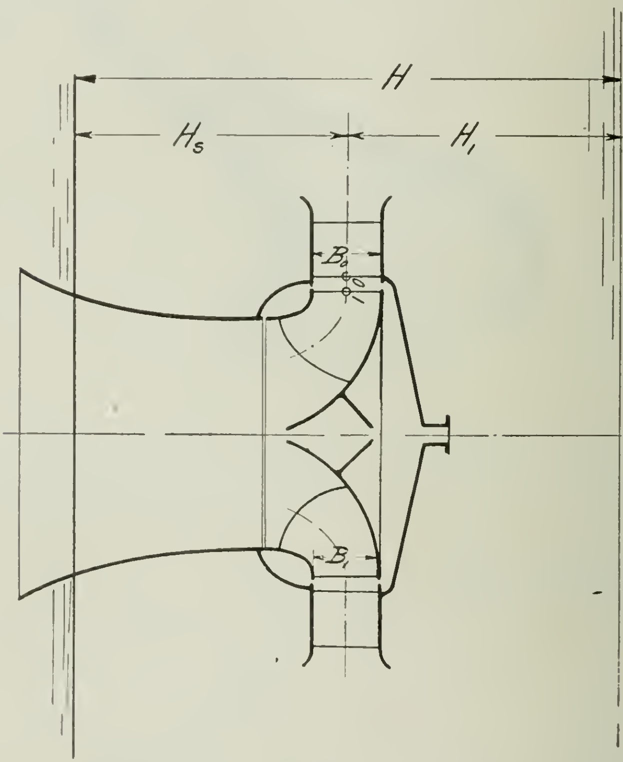

Fig. III

cavity filled with eddying particles will be formed, in which, even if there should be pressure in the rest of the stream, a partial vaccum will prevail, owing to the ejector effect of the stream. In such cavities deaeration will take place and intense corrosion due to the freed oxygen will set in.

When the bucket angle β_1 is small there is little that the designer can do, to eliminate the cavitation, for other considerations of design limiting the radial and peripheral lengths of the bucket

will not leave him much space for modification of the curvature. This brings before us at once the question of why small angles β_1 are used at all.

The answer to this question is given by Fig. 2. It is apparent from this figure that with all other things remaining the same the small angles β_1 will give us smaller peripheral velocities. As now all velocities vary with the head as its square root, it is clear that the designer will resort to the small angles in order to counteract the effect of the high head upon the speed of the turbine. He, therefore, is inclined to use small angles β_1 when designing high head turbines. In doing this, however, and particularly in using very small angles β_1 he introduces a source of trouble, namely, the almost certain cavitation, which he can control only in a limited degree.

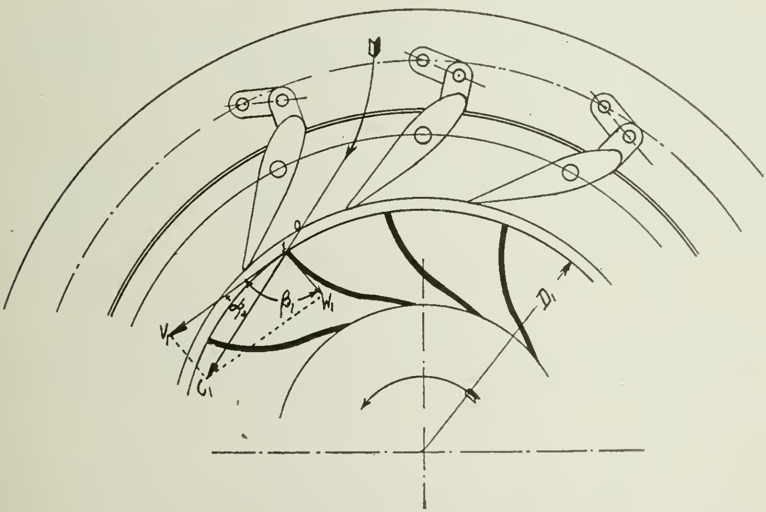

Fig. IV

But the bad effect of small angles β_1 on pitting does not end here. As namely with decreasing values of β_1 the pressure at the entry into the runner decreases, this pressure may easily drop down to zero or even become negative, in which case not only is cavitation more certain to set in, but deaeration will take place also at the entry into the runner.

Let p_1 pounds per square foot be the gage pressure at the entry into the runner, C_1 feet per second the velocity of entry, H the total head H_1 the static head at point *1*, H_{f1} the friction head lost above point *1*, H_s the suction head and γ the weight of one cubic foot of water, then the flow down to point *1* is characterized by the following balance equation (Bernoulli's theorem).

$$\frac{p_1}{\gamma} + \frac{C_1^2}{2g} = H_1 - H_{f1}$$

and hence the pressure at the entry into the runner is

$$\frac{p_1}{\gamma} = H_1 - H_{f1} - \frac{C_1^2}{2g}$$

Let us take into consideration only the normal or best efficiency operating conditions. Let us also assume that the turbine has been designed in such a manner that at these operating conditions both the s. c. shockless entry and perpendicular discharge are obtained (see foot-note), then the entrance velocity is determined by the following formula

$$C_1 = \sqrt{\epsilon g H}\sqrt{\frac{\sin\beta_1}{\sin(\beta_1 - \alpha_1)\cos\alpha_1}}$$

Herein is ϵ the hydraulic efficiency of the turbine, β_1 the runner angle and α_1 the angle under which the water approaches the runner (see Fig. 4).

From this equation we get:

$$\frac{C_1^2}{2g} = \frac{\epsilon H}{2}\,\frac{\sin\beta_1}{\sin(\beta_1 - \alpha_1)\cos\alpha_1} = \frac{\epsilon H}{1 + \cos 2\alpha_1 - \sin 2\alpha_1 \cot\beta_1}$$

and by substitution:

$$\frac{p_1}{\gamma} = H_1 - H_{f1} - \frac{\epsilon H}{1 + \cos 2\alpha_1 - \sin 2\alpha_1 \cot\beta_1}$$

For $H_1 - H_{f1}$ we may, without committing a great error, write $H - H_s$, so that the pressure head at the entry into the runner is approximately

$$\frac{p_1}{\gamma} = \left(1 - \frac{\epsilon}{1 + \cos 2\alpha_1 - \sin 2\alpha_1 \cot\beta_1}\right) H - H_s \quad \ldots\ldots (1)$$

In Fig. 5 the expression in the brackets has been shown graphically for certain angles α_1 against β_1, wherein the hydraulic efficiency ϵ has been assumed to be 0.94.

This is a high value, but today it is obtainable with well designed and well built turbines.

These curves can be used for the study of the pressure conditions at the entry into the runner under any head, if the scale of the ordinates is established and a horizontal line is drawn at a distance of H_s feet. Pressure heads above this line will then be positive (above atmospheric pressure) and those below will be negative (vacuum heads).

Note.—If we were to consider the case in a general way, that is to say, without any restrictions as to operating conditions and design, we would encounter very great theoretical difficulties, making an analytic treatment almost impossible.

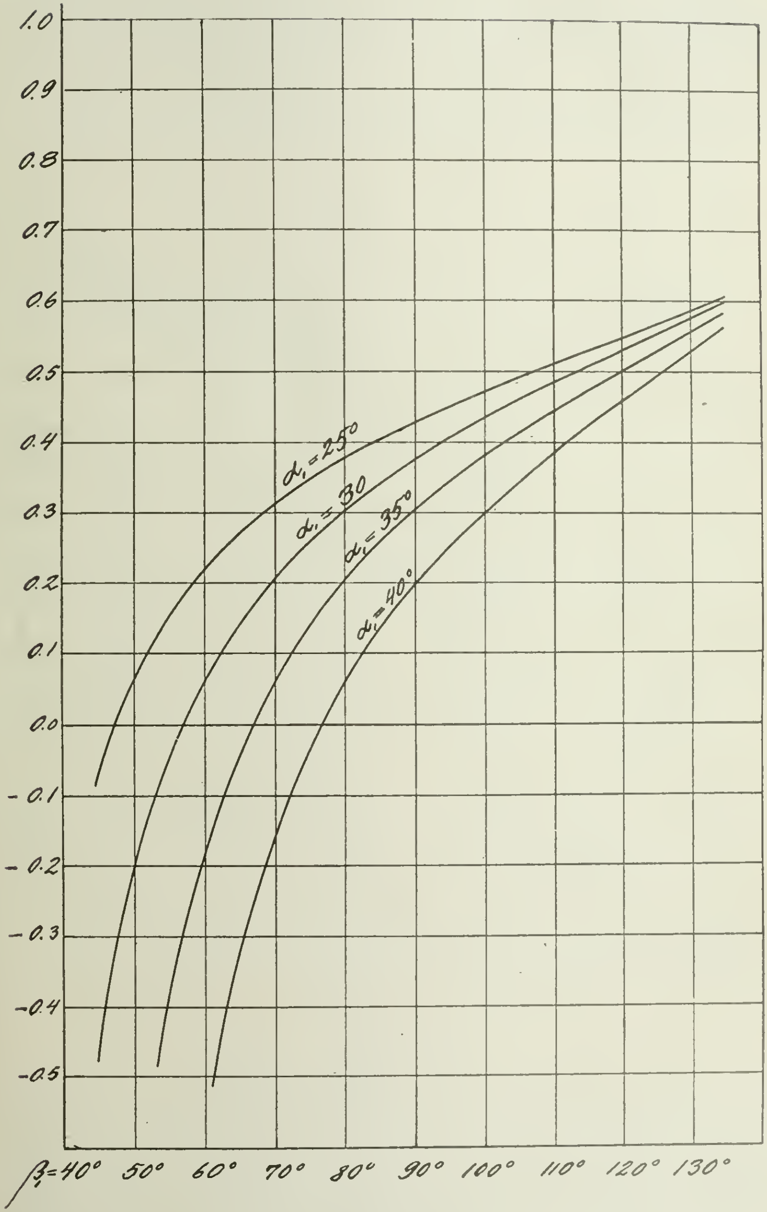
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
- 0.1
- 0.2
- 0.3
-0.4
-0.5
α1=25°
α1=30
α1=35°
α1=40°
β1=40° 50° 60° 70° 80° 90° 100° 110° 120° 130°

FIG. 5.

This has been done in figures 6, 7, 8 and 9 for turbines running under 25, 100, 250 and 500 feet head and suction heads of 20 feet in the last three cases and 10 feet in the first case.

From these curves we can find at what relations of β_1 and α_1 the pressure at the entry into the runner disappears.

If we disregard the hydraulic losses in the turbine, that is to

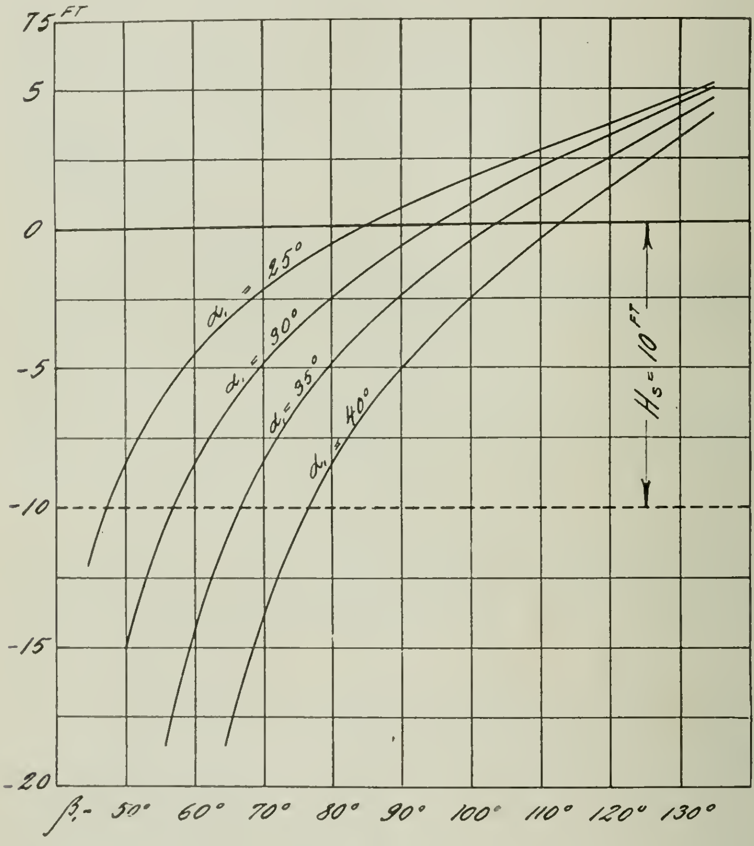

FIG. 6.

$H = 25$ FT. $H_s = 10$ FT.

say, if we assume for the hydraulic efficiency the value of 1, and also make $H_s = O$, then, as is known to every student of turbine theory, the pressure at the entry into the runner will disappear at $\beta_1 = 2\alpha_1$. Many designers satisfy themselves with the application of this rule, believing—without examining the given case any further that this will safeguard them against obtaining negative pressure. That they

will deceive themselves, at least in all cases where the suction head is relatively large, is apparent from the figures. Take, for instance, the curves of the turbine running under 100 feet head and with 20 feet suction head. There, with $\alpha_1 = 35°$ the pressure will become zero at approximately $\beta_1 = 80°$.

In low head turbines the suction head has the greatest effect on the pressure conditions. We have cases where the pressure will

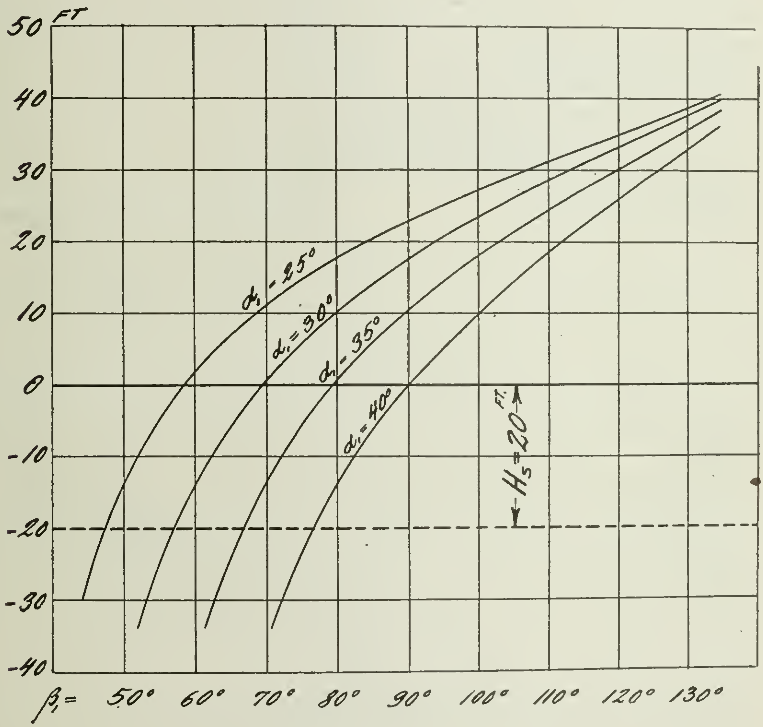

FIG. 7.

$H = 100$ FT. $H_s = 20$ FT

be negative regardless of how large β_1 is made. Only in high head turbines, where H_s is, in comparison with the total head, small, is its effect upon the pressure conditions or the critical values of $\beta_1 : \alpha_1$, almost negligible—but there is another factor, so far not taken into account, to neglect which would be a great mistake in high head turbines, whereas it is not important in low head turbines.

This factor is the sudden enlargement at the guide vane tips,

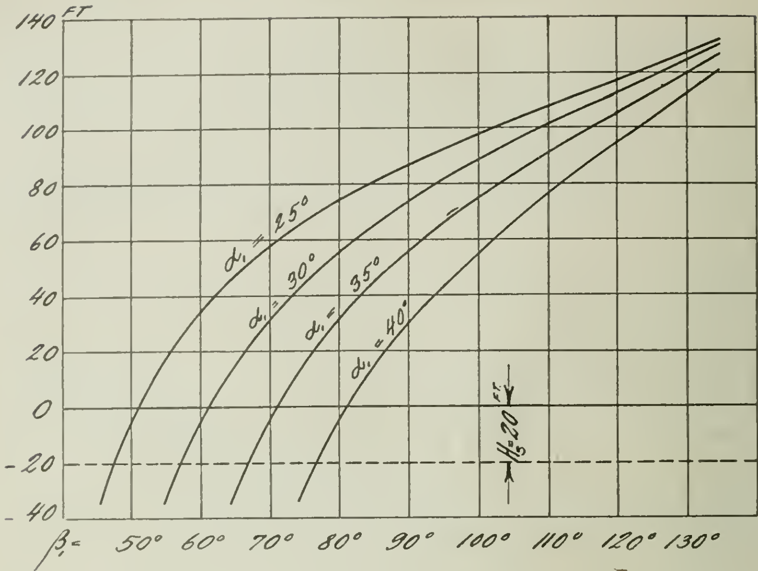

FIG. 8.

$H = 250^{FT}$ $H_S = 20^{FT.}$

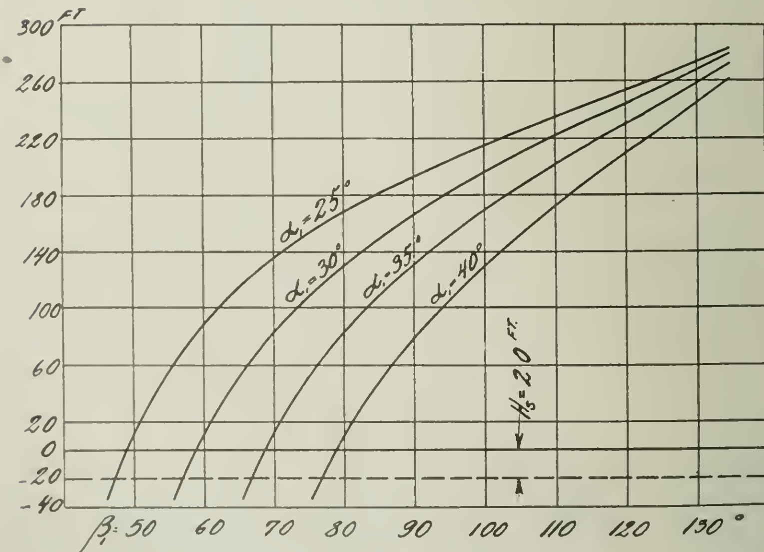

FIG. 9.

$H = 500^{FT.}$ $H_S = 20^{FT.}$

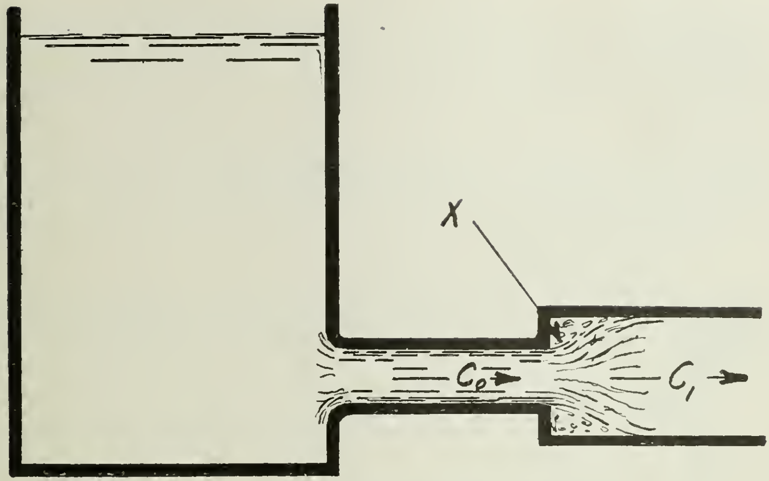

Fig. X

caused by the disappearance of the same at the point *O*, which enlargement is equivalent to that shown if Fig. 10.

It is a very well known fact that at point *X* of Fig. 10 a pressure drop is created—a partial vacuum, if the enlarged pipe discharges into the atmosphere. This pressure drop may be computed with an accuracy which is entirely sufficient for the case at hand as follows.

Since it has been established experimentally that in all cases where the sudden enlargement is relatively small the energy lost in it is equal to the head of the entire speed difference, we may assume this to be true also in the passage from *O* to 1 in the turbine. The energy lost there is then

$$\frac{(C_o - C_1)^2}{2g}$$

Now we may write the balance equation for the flow from point *O* to point 1 and find the pressure drop as follows: Energy at O + gains — losses = energy at 1.

Since there is, as a rule no level difference between *O* and 1, there is no gain and the balance equation is, therefore,

$$\frac{C_o^2}{2g} + \frac{p_o}{\gamma} - \frac{(C_o - C_1)^2}{2g} = \frac{C_1^2}{2g} + \frac{p_1}{\gamma}$$

$$\frac{p_o}{\gamma} = \frac{p_1}{\gamma} + \frac{C_1^2 - C_o^2 + (C_o - C_1)^2}{2g}$$

$$\frac{p_o}{\gamma} = \frac{p_1}{\gamma} - (C_o - C_1)\frac{C_1}{g}$$

Therefore, in the eddies created by the disappearance of the guide vane tips, the pressure head will be smaller than at the entry into the runner by approximately $(C_0 - C_1)\dfrac{C_1}{g}$ if C_0 is the velocity in the passage area which is reduced by the vane tips and C_1 is the velocity in the unrestricted passage area.

These two areas are:

$$A_0 = (\pi D_0 \sin\alpha_0 - nt)\, B_0$$
$$A_1 = \pi D_1 \sin\alpha_1\, B_1$$

wherein n is the number and t the thickness of the vanes, B_0 and B_1 the heights of the guide case and runner. Now we may write

$$(C_0 - C_1)\frac{C_1}{g} = (C_1\frac{A_1}{A_0} - C_1)\frac{C_1}{g} = 2(\frac{A_1}{A_0} - 1)\frac{C_1^2}{2g}$$

Hence

$$\frac{p_0}{\gamma} = \frac{p_1}{\gamma} - 2(\frac{A_1}{A_0} - 1)\frac{C_1^2}{2g} = H_1 - H_{t1} - \frac{C_1^2}{2g} - 2(\frac{A_1}{A_0} - 1)\frac{C_1^2}{2g}$$

$$\frac{p_0}{\gamma} = H_1 - H_{t1} - (2\frac{A_1}{A_0} - 1)\frac{C_1^2}{2g}$$

Let us disregard the difference, if there is any, between B_0 and B_1; α_0 and α_1 and also D_0 and D_1. Then

$$2\frac{A_1}{A_0} - 1 = \frac{2A_1 - A_0}{A_0} = \frac{2\pi D_1 \sin\alpha_1 B_1 - (\pi D_1 \sin\alpha_1 - nt)B_1}{(\pi D_1 \sin\alpha_1 - nt)B_1}$$

$$= \frac{\pi D_1 \sin\alpha_1 + nt}{\pi D_1 \sin\alpha_1 - nt}$$

$$\therefore \frac{p_0}{\gamma} = H_1 - H_{t1} - \frac{\pi D_1 \sin\alpha_1 + nt}{\pi D_1 \sin\alpha_1 - nt} \times \frac{\epsilon H}{1 + \cos 2\alpha_1 - \sin 2\alpha_1 \cot\beta_1}$$

$$\frac{p_0}{\gamma} = (1 - \frac{\pi D_1 \sin\alpha_1 + nt}{\pi D_1 \sin\alpha_1 - nt} \times \frac{\epsilon}{1 + \cos 2\alpha_1 - \sin 2\alpha_1 \cot\beta_1})H - H_s \ldots . (2)$$

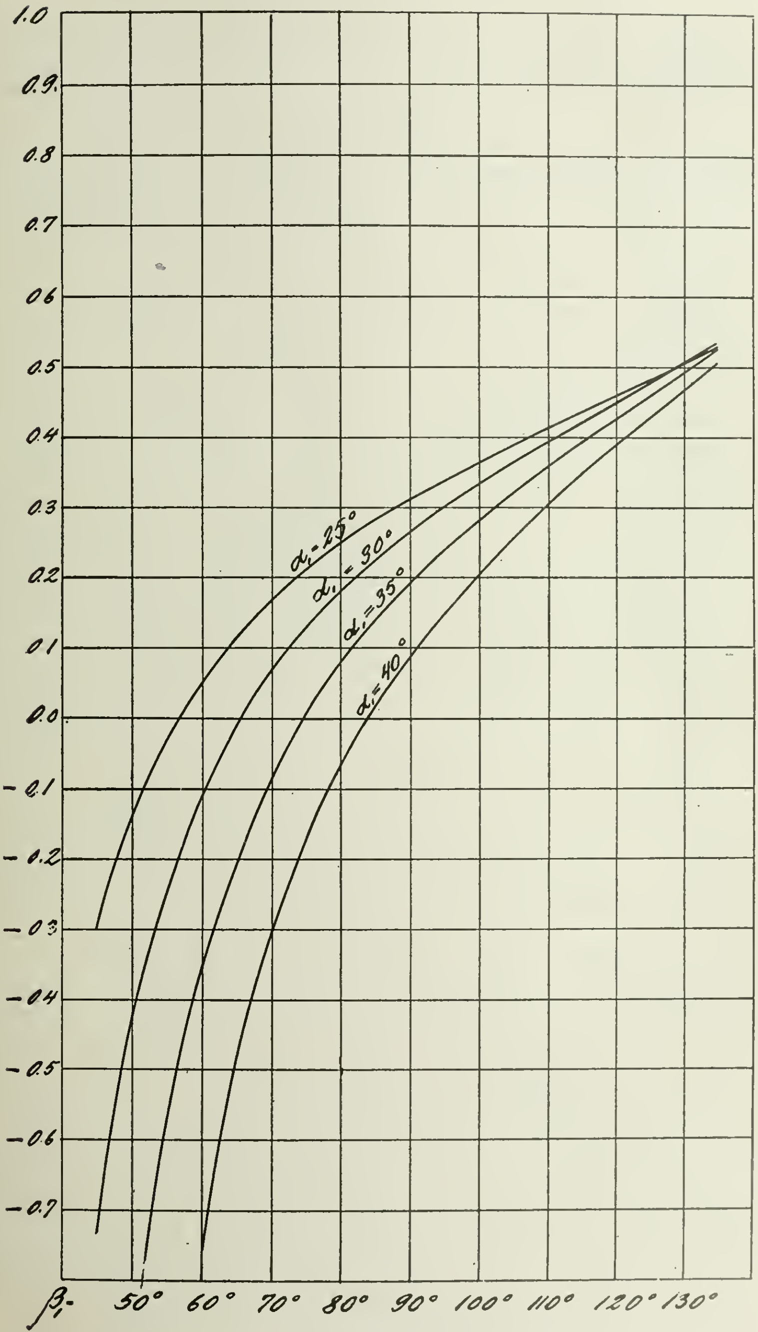
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
$\alpha_1 = 25°$
$\alpha_1 = 30°$
$\alpha_1 = 35°$
$\alpha_1 = 40°$
β_1 - 50° 60° 70° 80° 90° 100° 110° 120° 130°

FIG. 11.

Let us assume that the turbines mentioned before have runner diameters of 48″ and that there are 24 guide vanes ¼″ thick at the ends, then the factor $\dfrac{\pi D_1 \sin \alpha_1 + nt}{\pi D_1 \sin \alpha_1 - nt}$ has for $\alpha_1 = 25°$, $30°$, $35°$ and $40°$ the value of 1.205, 1.172, 1.148 and 1.132, respectively.

The curves in Fig. 11 show graphically the values of the bracket in formula (2). Drawing again at a distance of H_s feet horizontal lines, after the scale of the ordinates has been fixed, we can easily find at what values for β_1 the pressure in the eddies at the vane tips becomes zero. See Figs. 12, 13, 14, 15.

Assuming the same suction heads as before and comparing with curves in Figs. 6, 7, 8 and 9, we shall readily see that now the critical values of the angle β_1 are substantially higher than before. In every case the critical ratio of $\beta_1 : \alpha_1$ is larger than 2. This has very seldom been taken into account by turbine designers and many turbines have been designed with angles β_1 at which the pressure at point O dropped to or below that of the atmosphere—even when the turbine was running under normal conditions which formed the basis of the design and computing. The consequence was that deaeration took place in the eddies formed by the guide vane tips and pitting set in not only at the vane tips but also at other places; in the runner and draft tube, where the liberated air particles carried along by the streams came in contact with the metal.

A very remarkable case came to the attention of the writer several years ago, where it was quite apparent that the pitting of the draft tube close to the runner exit was caused by the deaeration in the eddies at the guide vane tips. The turbine, installed under a very high head, was designed as a low speed wheel, *i. e.*, with a small angle β_1. There were 22 guide vanes and 20 runner buckets. After a short time of operation it was discovered that the draft tube close to the runner was pitted at 22 spots, equally spaced on the circumference, the attacked spots being all of equal size. In course of time the spots grew larger and larger until they joined and the draft tube pitted all around.

The fact that there were 22 spots at which pitting started proves beyond any doubt that the pitting was caused by the eddies at the guide vanes—there being 22 guide vanes and 20 runner buckets. The oxygen which liberated itself in these eddies owing to the partial vacuum existing there passed through the runner and hitting the draft tube always at the same spots caused at the spots an intense electrolytic action, destroying the iron.

Analyzing and comparing the curves in the Figs. 12, 13, 14 and 15, we shall readily see that high head turbines are particularly sensitive as regards the pressure conditions at the discharge from the guide vanes, if, as we are inclined to do, we use small angles β_1 for the sake of counteracting the effect of the high heads on the speed of the wheel. Even a little change of β_1 may then cause the pressure to fall considerably below that of the atmosphere. Thus

an error in the core box made by the pattern maker, or an error in setting the cores made by the moulder—even unequal shrinkage of the casting may change the actual angle β_1 from that prescribed by the designer sufficiently to cause trouble.

Suppose for instance that the 500-foot turbine was designed with $\beta_1 = 70°$ and $\alpha_1 = 30°$ (and turbines were often built with a more dangerous ratio of angles than this) then, as we can see from

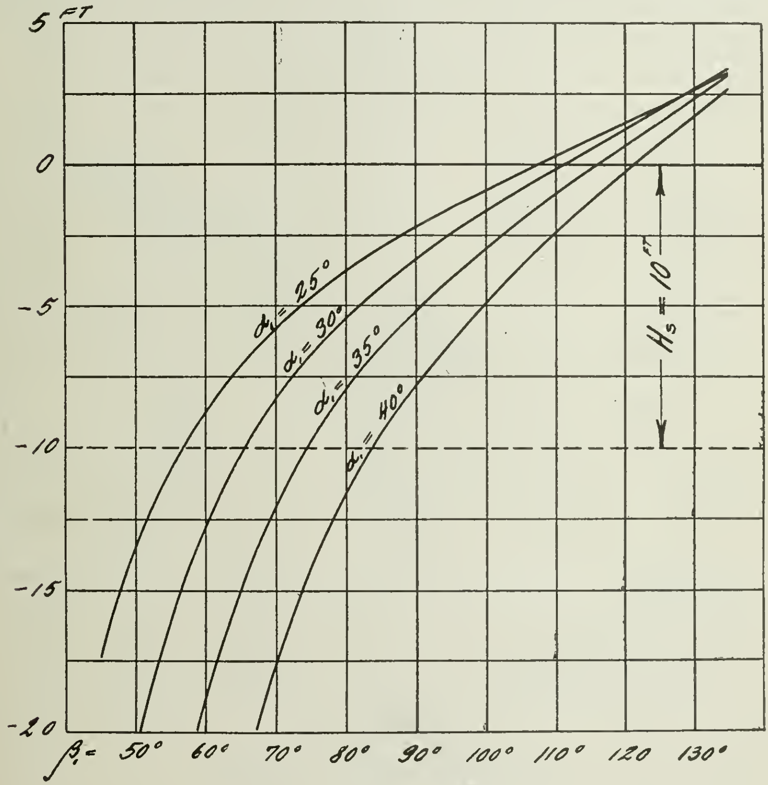

FIG. 12.

$H = 25$ FT. $H_s = 10$ FT.

the curves of Fig. 15, the pressure head at point *O* is positive, namely, about 16 feet water column. Deaeration should therefore not take place. But let there be an error made of only 4° so that β_1 is actually 66° instead of 70°, then, as we can see from the curves, a negative pressure head of about 15 feet is obtained and intense deaeration must be expected.

Low head turbines are, by far, less sensitive. Let us consider the turbine operating under 25-foot head and let us suppose that

the angle β_1 is 130° and α_1 is 40°. The pressure at point O is then 1.75 feet. An error of 4°—as before—would not change the pressure materially. An error of 8° would bring the pressure down to zero and with an error of 10° a negative pressure head of only —0.25 feet would be obtained, with only a slight deaeration.

Even, if owing to a relatively great suction head the pressure at point O of a low head turbine should be negative regardless of what values for the angles may be used, the deaeration will be slight because the vacuum will be small even in the most extreme cases.

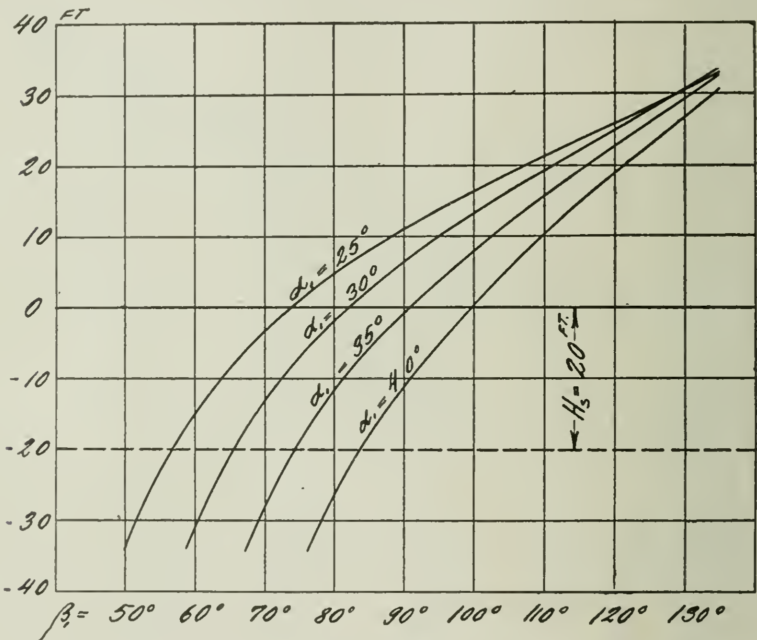

FIG. 13.

H = 100 FT. H_s = 20 FT

If, for instance, the same 25-foot head turbine had a suction head of 20 feet, the vacuum would be only 8.25 feet. If the angle β_1 was made equal to 135° a vacuum head of 6.75 feet would be obtained; if it were made only 110° a vacuum of 12.3 feet would be obtained.

This shows clearly that low head turbines are very insensitive as regards deaeration even within very large ranges of β_1. It is also clear that the low head turbines will pit very seldom while high head turbines pit frequently and that, if the first pit, it will be mainly due to a relatively great suction head while the second pit because too small angles β_1 are used.

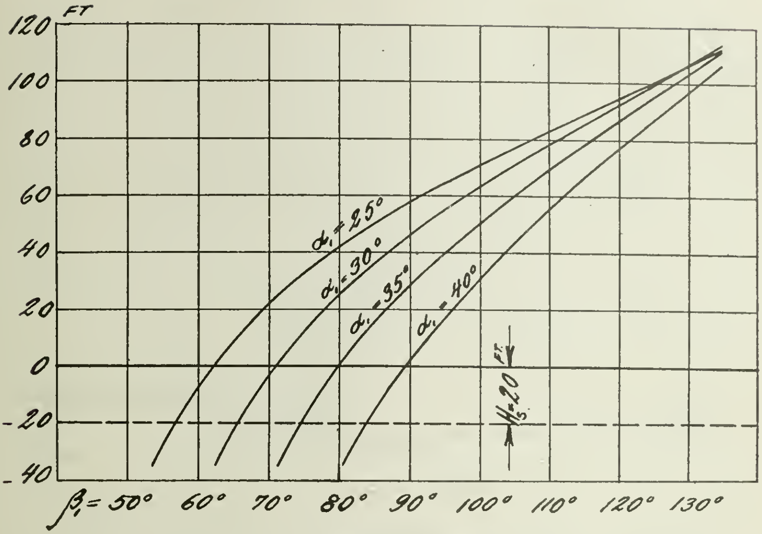

FIG. 14.

$H = 250$ FT. $H_s = 20$ FT.

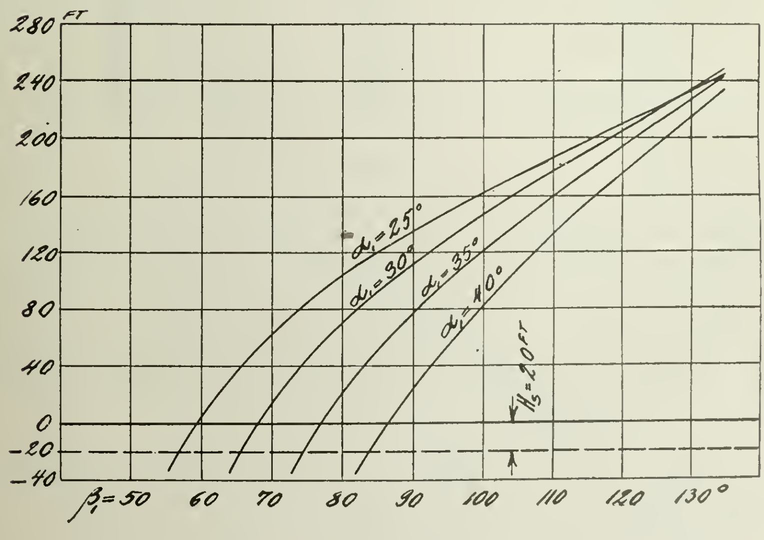

FIG. 15

$H = 500$ FT. $H_s = 20$ FT.

The pitting of high head turbines will be much more intense than that of low head turbines not only on account of the greater vacua obtained but also on account of the much greater velocities of flow. The water flowing at the high rate through the wheel, at which it always does in high head turbines, will wash out instantly the corroded particles, and by thus exposing continually fresh surfaces it will aid the process of corrosion mechanically. In addition, the local shocks and impulses with which the creation of eddies is always connected and which will be especially great when the speeds of flow are great, will raise the potential at these points, thus increasing the electrolytic action still more. It is namely an established fact that when water impinges on surfaces in the presence of air an electric potential is created.

That a low pressure at the entry into the runner will also make

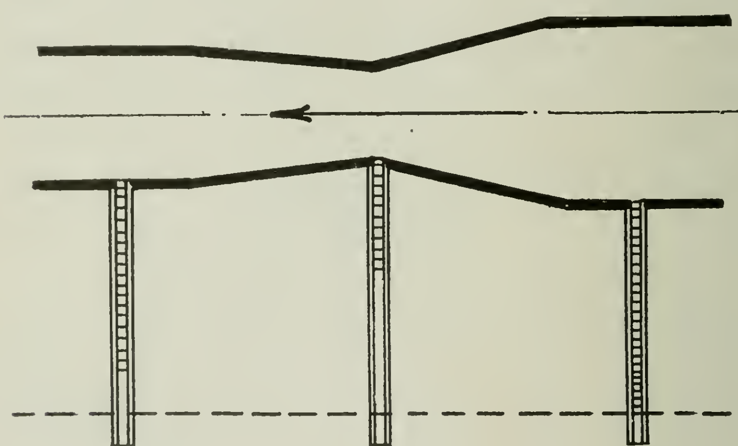

Fig. XVI

cavitation and pitting at the above-mentioned sharp turns of the buckets more certain is self evident, but the runner buckets are frequently attacked at other places, and the cause of this cannot be traced back to the pressure conditions at the entry. This happens at such places where a throttling effect is introduced into the passage either by faulty design of the bucket surfaces or by errors in the building of the runner. Fig. 16 represents diagrammatically this case. The contraction may easily be large enough to cause the pressure to drop below that of the atmosphere.

In many low head turbines working under high suction heads the runners have pitted only because the bucket surfaces were irrationally curved and such contractions occurred. But most of all it is again the high head turbine where this happens.

High head turbines are almost always cast in one piece and it may easily happen that the cores, even if the core box should be correct, are not set right in the mould or the core box may not be

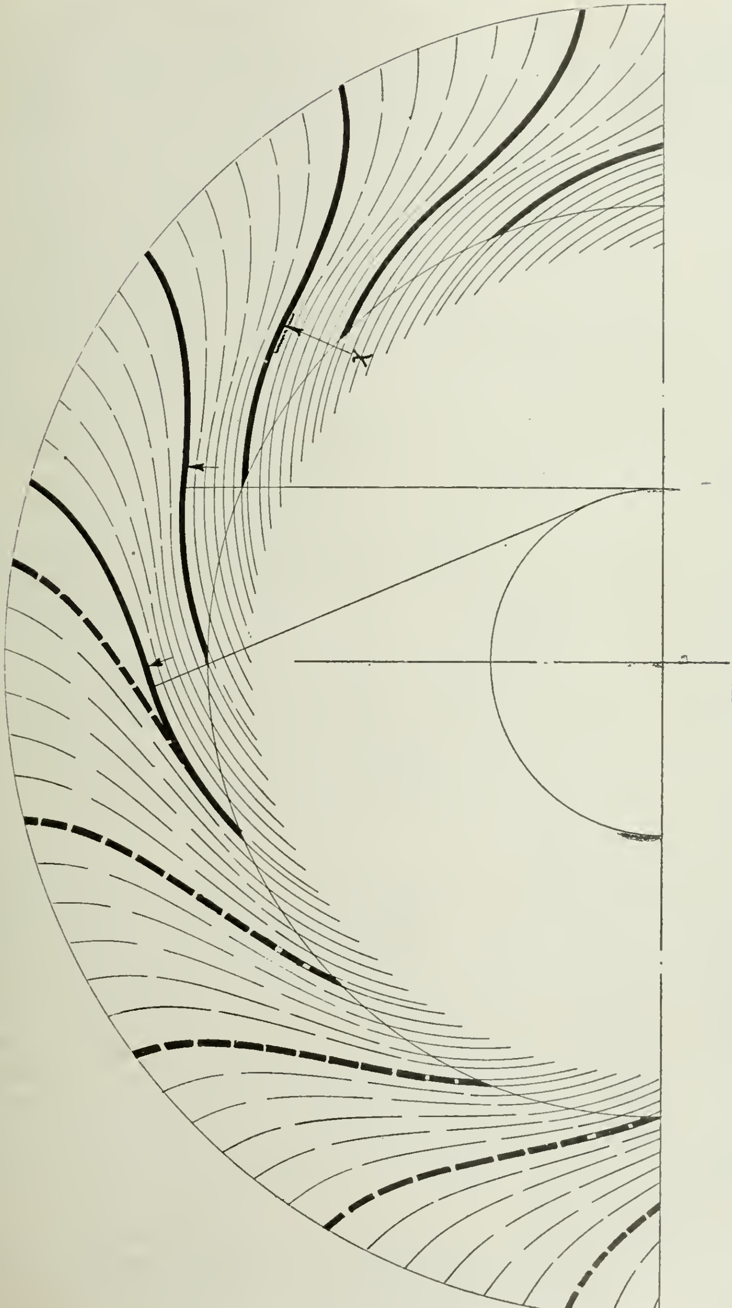

Fig. XVII

made exactly according to the drawing or that the shrinkage of the cooling metal is uneven with the result that such contractions in the passages occur. This happens frequently near the discharge ends of the buckets, where the designer is liable to design the buckets with parallel tips. Some designers even take great pains to obtain this parallelity at almost any cost, and in this they are supported by most of the European authorities who recommend it with emphasis. It is namely claimed that in order to obtain parallelity of flow at the entry into the draft tube the bucket ends must be parallel far back to a point opposite the end of the next bucket and even a little further. See arrow in Fig. 17—full lines. But a glance at the buckets drawn in dotted lines will convince us that parallelity of flow or sufficient guidance will be assured even if the buckets begin to curve back much sooner. We must namely not forget that the water discharges from the runner all around in a complete circle and that therefore it is only necessary to guide it for a short distance at several places to obtain strictly defined paths throughout the entry into the draft tube.

Even from the point of view of efficiency the requirement of long parallel bucket ends far back cannot be upheld, for it is a very well known fact that a nozzle is hydraulically superior to a straight pipe. The author not only does not hesitate to design the bucket ends with a certain degree of nozzle effect, but recommends this instead of the "parallelity."

In the low head turbines built in this country the bucket ends have very seldom and of late never been designed with this parallelity. As a matter of fact, a very marked nozzle effect has been used in many cases with excellent results. The author knows of some Holyoke tests which, while scientifically not sufficiently conclusive in this respect (these tests were primarily carried out for other reasons), seem to prove that nozzle effect increases the efficiency of the runners.

As far as pitting is concerned, the parallelity, if exaggerated, is decidedly harmful. As, namely, the turbines are always installed with a greater or smaller suction head, the pressure at the discharge from the buckets will be below that of the atmosphere and with parallel bucket ends this same reduced pressure will prevail far back. Therefore, even a little irregularity in the surface—slight depressions and protuberances may cause cavitation with an increased vacuum and localized deaeration will take place. The effect of the sudden disappearance of the bucket tips will be more pronounced than if there were a slight convergence in the passage area throughout to the final point of discharge. In fact, quite intense pitting occurs in such runners opposite the edge of the next bucket. See Fig. 17, point X.

The rule of parallelity is also oversensitively applied to the design of the guide vanes—with the same bad effect in all cases, in which the pressure at point O is low on account of a small value $\beta_1 : \alpha_1$. Very often the designers draw the vanes up in only one

position: either at the normal or maximum gate opening, and they do not investigate the passage areas at the other gate openings at which very frequently a throttling effect is obtained—while at the normal or maximum gate opening parallelity far back existed.

In line with this is the idea, often carried out, that the individual buckets and guide vanes should also be parallel at the ends—that is to say, of uniform thickness—not pointed. That this increases the bad effect of the sudden enlargement by making the eddy longer and giving the air more chance to escape is self evident.

Some designers place the guide vane tips as close to the runner buckets as they can without mutual interference, and again some authorities in Europe recommend doing this claiming that otherwise the water would not be guided properly as it enters the wheel. This is quite analogical to the view taken by them in regard to the parallelity of the bucket and guide vane ends; and equally wrong. The water streams, forming a complete ring, follow a definite path if they are started in a certain and the same way at several points of the periphery of the same circle and then are left alone. (If the height of the annular space is constant, then the paths are logarithmic spiral curves, *i. e.,* curves which cut all concentric circles at the same angle.) The author has used, in the high capacity high speed turbines designed in recent years by him, very large radial clearances between the vanes and buckets with excellent results as far as efficiency is concerned. The further fact that the actual speed and capacity of the wheel checked very well with the computed values proves that nothing was lost in the definiteness of the problem as regards the paths taken by the water streams in the clearance space.

Moving the guide vanes sufficiently away from the runner, so that the streams join into one before they enter the runner, will not only have a beneficial effect upon the efficiency of the turbine by making the flow through the runner more orderly, but it will also reduce the pitting. It is, namely, clear that when the runner buckets cut through the eddies caused at the vanes, hydraulic shocks will occur and these will create or increase the existing potential, as water hitting solid bodies does when air is present.

From the above it appears that the designer of water turbines has control over pitting to a great extent. Even though he cannot do away with it entirely in every case, he can at least reduce it to a minimum by observing the following rules in the design of the turbines:

1. Avoid small angles β_1 altogether in high head turbines and do not use very large angles α_1.
2. Do not place the turbine any higher above the tail race than is absolutely necessary.
3. When designing low head runners which you may want to use at different occasions and under different conditions, use the largest angles β_1 possible.
4. Do not design the buckets and guide vanes with an exag-

gerated parallelity at the ends; rather introduce a slight nozzle effect so that the flow will be accelerated throughout.

5. Make the guide and bucket vane tips pointed so that the eddies will be as short as possible.

6. Make the guide vane ends as thin as consideration of strength and building will allow.

7. Place the guide vanes far enough from the runner to allow the streams to join into a ring before they enter the runner.

8. Avoid all sharp turns and depressions. Check the design of the runner surface carefully to determine whether there is a throttling effect, which should be avoided absolutely. Do the same after the runner is built.

9. Examine the guide vanes in different positions and make sure that there is no place where the opening is smaller than at the discharge point.

The intensity of pitting depends also on the potential which we get from other causes than simple chemical action. We can, therefore counteract pitting by removing these causes if it is possible to do this. Thus:

1. We should try to get castings as homogeneous as possible both in chemical and physical structure and also as free of impurities as possible.

2. Where pitting is liable to occur, the parts should be machined all over. Finishing, like any other strain, changes the physical structure of the metal and, therefore, partial finishing causes potential—even scratches and blows will do it.

3. The castings should be designed and moulded in such a manner that uniform cooling is secured. Strains due to unequal cooling will create potential.

DISCUSSION.

W. E. Williams, M. W. S. E.: The author indicates that a wide space between the runner and the gate blades is no objection. Where would that width become objectionable? Would it be possible, for instance, to eliminate the guide buckets entirely provided you had a means of controlling the turbine by the supply of water?

Professor Zowski: It is essential that the water be guided in such a manner that it will enter the runner under the proper angle. In turbines having a spiral casing it is possible to guide the water properly by the spiral casing alone, that is to say, by giving the spiral casing the proper shape we can get the desired angle of entrance at the runner without any additional guiding by vanes—but as the guide vanes are best adapted to the regulation of the capacity—when built as they now always are being built, in the form of the flutter gates, they are always used. In open and cylindrical flume turbines guide vanes are necessary both for guidance and regulation.

Mr. Williams: Within the last few years a wide change has come over the designs of centrifugal fans in the direction in which

the buckets have been placed in the runners. Have the last few years of experimentation in water turbines brought about any such radical change as has been brought about in the shape of the centrifugal fans for air?

Professor Zowski: Considerable changes have been brought about in the design of the turbine buckets in recent years, but these changes were of an entirely different nature than those in the design of centrifugal pumps and fans.

The question with the latter is and was, and, no doubt, this is what you have in mind, whether the buckets, viewed in the radial section, should be curved backward or forward and how far one should go in the one or the other direction.

In water turbine practice the changes affected more the shape of the buckets as viewed axially—at least in high capacity runners which in recent years have been improved upon so much. The amount of drawing down of the buckets in the axial direction and of bulging them out radially at the discharge and the giving to them a spoon-like shape are the main characteristics.

Both forward and backward curved buckets are used—depending on the speed requirement—but owing to a better understanding of the pressure conditions—discussed in the paper—the high head wheels are now seldom curved forward as much as formerly.

IN MEMORIAM

WALTER KATTE

Honorary Member, W. S. E.

Died March 4, 1917.

Walter Katte was born in London, England, November 14, 1830. He was the son of Edwin Katte, and the grandson of Edwin Katte, a political refugee from Prussia during the reign of Fred-

erick the Great. His mother, Isabel Chambers, was the granddaughter of John Chambers, a celebrated boat builder on the Thames River, London. Walter Katte was educated in Kings College School, London, and after graduation spent three years as an apprentice in the office of a London civil engineer.

In 1849 he came to this country and entered American railroad service as clerk and draughtsman for the chief engineer of the Central Railroad of New Jersey, from Whitehouse to Easton, Pa. Later he served as a rodman and assistant engineer on the Belvidere & Delaware Railroad. In the early '50's he acted as engineer for a land development company and laid out the town of Deerman, now called Irvington-on-Hudson, N. Y.

During the three years following 1854, he was chief assistant engineer on the western division of the Pennsylvania Railroad. He later acted successively as resident engineer of the Pennsylvania State Canals; as assistant engineer of the Pittsburgh, Fort Wayne & Chicago Railroad, and of the Pittsburgh & Steubenville Railroad until the breaking out of the Civil War.

In 1859 he was married in Greensburg, Pa., to his first wife, Margaret Jack, who died in 1864, leaving one son.

During the years 1861 and 1862 he served as a colonel of engineers in the Union Army, being commissioned from civil life to a staff position. He was assigned to bridge work in Washington and at various points in Virginia and Maryland. He was the engineer in charge of the construction of the so-called "Long Bridge" over the Potomac River at Washington. While in charge of the construction of this bridge he had an experience with the great cavalry leader, General Watts Kearney. The general, returning one night to his regiment, which was quartered across the Potomac, sent his orderly ahead to demand passage over the bridge and he received word that the bridge was not in condition for traffic. He immediately rode his horse at full speed on to the bridge and upon being peremptorily stopped by Col. Katte, demanded an explanation as to why he was not permitted to proceed. Col. Katte quietly explained that a gap of 100 feet or more in the bridge structure would prevent his further progress except by swimming. Commenting editorially, a New York daily paper said, "In the Civil War nothing was more important to the safety of Washington than keeping the railroads and bridges in its neighborhood in perfect shape. This work Col. Katte supervised efficiently. Though not won on the battlefield, his military title stood for active, energetic work in the interests of military defense."

In 1863, Col. Katte was occupied as chief engineer of the Lewiston Branch of the Pennsylvania Railroad and later as resident engineer and engineer of bridges and buildings on the Northern Central Railroad from Baltimore to Elmira.

Col. Katte compiled and wrote the first Carnegie Pocket Companion published, and recently, at the request of the Carnegie Steel Company, wrote the history thereof, as follows:

"In 1865 to 1868, I was resident in Pittsburgh as engineer and secretary of the Keystone Bridge Company. In 1868 that company and Union Iron Mills of Pittsburgh (Carnegie Bros., Kloman, Phipps & Co.) decided to enter the western field in competitive business and to establish an office and representative in Chicago for that purpose; I was chosen for that position. The Keystone Bridge company had at that time already under contract the manufacture and erection of the superstructures of the Hannibal & St. Joe Railroad Company's bridge over the Missouri River at Kansas City, and the Illinois Central Railroad Company's bridge over the Mississippi River at Dubuque, Ia., also was negotiating contracts for bridges, later consummated for Mississippi River bridges at Keokuk, Ia., Louisiana, Mo., and St. Louis, Mo.

"I proceeded to Chicago and opened there the western office of the Keystone Bridge Company and the Union Iron Mills of Pittsburgh, Pa., and took personal charge as agent and representative of the field operations under these contracts.

"In 1870, negotiations for the great steel arch bridge over the Mississippi River at St. Louis were being actively promoted by Mr. Andrew Carnegie and myself, and finally consummated in the execution of a contract, signed by Capt. James B. Eads, as president of the Illinois & St. Louis Bridge Company, and by myself on the part of the Keystone Bridge Company, under the terms of which the Keystone Bridge Company undertook and obligated itself to perfect the mechanical details of the shop drawings of the superstructures, supply all materials for, and manufacture of same, design plans for erection, and to erect it and assume all responsibility for the successful completion of the erection.

"I was assigned to take personal charge as resident engineer of said erection. As the responsibility for the successful consummation of same was of extreme gravity, I felt the paramount necessity of my personal presence on the work continuously, which, of course, resulted in the closing of my office in Chicago and removal of same to St. Louis, which was effected early in 1871, and the joint western office of the Keystone Bridge Company and the Union Iron Mills of Pittsburgh, Pa., was opened under my charge at No. 211 Washington avenue, St. Louis, Mo.

"About this time, or a little later, Mr. Thomas Carnegie suggested to me his desire to issue a handy 'Pocket Book' as a desirable assistant to engineers and architects in making proper selections, suited to their requirements, of the various products of the Union Iron Mills and asked me to compile the Mss. for it, which I did. It was all written by my own hand from time to time in such leisure moments as were available, notwithstanding the pressing demands of my every day work, most of it done at home in evenings—and that's about all the early history that this little progenitor has to claim. It proved, however, a great success when issued and there was, so Thomas Carnegie told me, a great demand for it, and he wrote me that he had received many letters from engineers and

architects using it—highly extolling its usefulness and wondering why such a handy little 'vade mecum' had not been issued long before."

While living in St. Louis, Col. Katte was married to Elizabeth Pendleton Britton, daughter of the Hon. James H. Britton, a prominent banker and later mayor of that city.

After the completion of the St. Louis Bridge, Col Katte was called to New York City to take the position of chief engineer of the New York Elevated Railroad Company, and during the years 1877 to 1880 built the initial portions of the Third avenue and Ninth avenue elevated railroads, which were the first elevated steam railroads.

His next work was the construction of the New York, Ontario & Western Railroad from Weehawken, N. Y., to Middletown, N. Y., then the building of the West Shore Railroad from New York to Buffalo, which was followed by the construction of the Jersey Junction Railroad, connecting the West Shore Railroad with the Pennsylvania Railroad at Jersey City. This work occupied his time between 1880 and 1886.

In 1886, he became chief engineer of the New York Central & Hudson River Railroad Company, which at that time absorbed the West Shore Railroad. Col. Katte's most important work while in the employ of the N. Y. C. & H. R. R. Co., was the four tracking and depressing of the tracks in New York City, north of the Harlem River, this work being known as the Harlem Depression; the construction of the four track steel viaduct in Park avenue, New York City, and the four track drawbridge over the Harlem River, which is still the largest drawbridge in existence. In 1898 Col. Katte resigned his position with the New York Central Company and in his letter of resignation stated, "The recent absorption of other railroad lines into the Vanderbilt System had so multiplied the duties of the office of the chief engineer, that he felt a younger man was necessary for the work." In accepting his resignation, Hon. Chauncey M. Depew, then president of the railroad company, said, "Col. Katte is one of the foremost engineers in the world. He is still connected with the New York Central & Hudson River Railroad Company as consulting engineer and will be as long as he lives."

Col. Katte was one of the original thirteen founders of the Western Society of Engineers and was but recently elected an Honorary Member. He was an early member of the American Society of Civil Engineers and served two terms as a director thereof. He was also a member of the British Institution of Civil Engineers.

During his active engineering life, Col. Katte made frequent contributions to technical papers and to the transactions of the national engineering societies. He published one of the first sets of standard specifications for railroad construction work. Several U. S. patents were taken out by Col. Katte, the one in most general use being his so-called "Three tie rail joint."

April, 1917

Important daily papers at the time of Col. Katte's death were unanimous in their expression of the fine quality of his engineering work, one commenting editorially as follows:

"Col. Katte was a fine American, a great railroad builder and had won first place among our civil engineers. . . . He knew and cared little about the devious ways of financing railroads; everything about construction and operation. Half a century of such activity fairly earned a period of repose. Col. Katte's later years were peaceful, calm, uneventful. He will live in the memory of his profession as a man who saw things clearly and who did things thoroughly. That is, from the practical viewpoint, the highest of encomiums."

Col. Katte enjoyed nearly nineteen years in quiet retirement. His health was excellent with the exception of almost total deafness; his mind alert and vigorous; his spirit strong and serene up to the day of his death.

He died at his home, No. 784 Park avenue, New York City, and is survived by a widow, two sons and a daughter.

PROCEEDINGS OF THE SOCIETIES

Minutes of the Meetings

Meeting No. 966, April 2, 1917.

The meeting was called to order at 8:15 P. M. by First Vice-President Roper, with about fifty members and guests present. The speaker of the evening, Dr. Wilhelm Miller, was then introduced and presented his paper on "Landscape Gardening in the Middle West," which was illustrated by lantern slides. The meeting adjourned at 10:00 P. M.

Meeting No. 967, April 16, 1917.

The meeting was called to order about 8:10 P. M. by Chairman Maury, of the Hydraulic, Sanitary and Municipal Section, with about 100 members and guests present.

The Secretary announced that the following had been elected to the grades indicated:

No. 5—Miles H. Mann, Terre Haute, Ind. . . . . Affiliated Member
No. 13—Lawrence J. McHugh, Chicago (Transfer from Student) . . . . Junior Member
No. 15—Emil J. Schmidt, Chicago . . . . Junior Member
No. 16—Frederick K. Copeland, Chicago (Transfer from Associate) . . . . Member
No. 17—W. F. M. Goss, New York (Transfer from Associate) . . . . . . Member
No. 18—William L. McNamara, Chicago . . . . Student Member
No. 19—Walter S. Lacher, Chicago (Transfer from Associate) . . . . . . Member
No. 20—Walter Buehler, Chicago . . . . Member
No. 21—Elmer W. Hildebrand, Chicago . . . . Student Member
No. 22—Edwin S. Dawson, Chicago . . . . Junior Member
No. 25—Charles S. Hall, Chicago (Transfer from Associate) . . . . Member

and that the following had made application for membership in the Society:

No. 23—Isadore Solomon, Chicago.
No. 24—George Sheppach, Chicago.
No. 26—Henry L. Potter, Chicago.
No. 27—James E. Noonan, Chicago.
No. 28—Tenney S. Ford, Chicago.
No. 29—A. L. Cummings, Chicago.

The chairman then introduced the speaker of the evening, Mr. Charles H. MacDowell, who read his paper on "American Research Methods." Discussion followed by Dr. Henry W. Nichols and Messrs. Wilsnach, W. W. De Berard, J. W. Mabbs, Levy, M. L. Carr, H. E. Goldberg, M. D. Kolyn, James N. Hatch and Sutton Van Pelt. The meeting adjourned about 10:30 P. M.

Meeting No. 968, April 23, 1917.

This was a joint meeting of the Chicago Section, A. I. E. E., and Electrical Section, W. S. E., and was called to order by Mr. E. W. Allen, of the Electrical Section, W. S. E., at about 8:00 P. M., with about sixty members and guests present. The speaker of the evening, Mr. Norman T. Wilcox, was then introduced and presented his paper on "Economic Industrial Applications of Electricity," which was illustrated by lantern slides. Discussion followed by Messrs. George W. Jones, Olmsted and James N. Hatch.

The meeting adjourned about 10:00 P. M.

E. N. Layfield, Secretary.

BOOK REVIEWS

Mechanical Engineering, Columbia University. McGraw-Hill Book Company, New York, 1915. 258 pages, 6 inches by 9 inches. Price, $3.00.

The author states in the preface that he has considered it a duty to preserve the history of the development of the direct-acting steam pump and the results of his experience, extending over thirty years in that line, and that he feels confident that the book will supply much information that might be looked for elsewhere in vain. There has been comparatively little written on the direct-acting pump, it being regarded as uneconomical and looked upon abroad with contempt. It has had a field, however, in this country on account of the greater abundance of fuel and the author thinks that while this field is being encroached upon, it will not be entirely displaced.

The contents are as follows:

Chapter 1.—Development of the Direct-Acting Pump.

Chapter 2.—Performance Factors.

Chapter 3.—Classification and Types.

Chapter 4.—Pump End Details.

Chapter 5.—Steam End Details.

Chapter 6.—Service Conditions vs. Various Types.

Chapter 7.—Duty.

Chapter 8.—Operation and Adjustment of Direct-Acting Pumps.

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THE NATURE OF THE POWER REQUIREMENTS OF THE ELECTROCHEMICAL INDUSTRY

*By Mr. F. A. Lidbury.**

The subject that I am going to talk about this evening is one of vast importance, not only from an engineering point of view, but from a national point of view. It is a subject that is rather difficult to treat the way I am going to try to treat it in its entirety and as a whole, because although one is apt to get into a habit of grouping together all those industries that are known as electrochemical industries, yet on analysis they are found to differ considerably in reference to the power problem. And yet it is only by looking over the whole field that we can get any clear idea of the relation between the existence of power at reasonable prices and in considerable quantities and the possibility of growth and extension of those industries. This may lead to a certain amount of confusion in that any generalizations that we make are bound to have some exceptions, though the very exceptions are apt to illustrate some of the general conditions that it is necessary for us to observe in considering the relations between the electrochemical industries and power supply.

Now, I am going to ask your kindness to bear with me while I go very shortly over the electrochemical industries and their importance, because I find that many engineers do not know very much about the electrochemical industries, and still fewer engineers know the least thing about their enormous importance, not *per se*, but in respect of the indispensable nature of their products in many branches of industry.

Electrochemical industries, roughly speaking, can be divided in one way into three classes. First of all, the class which you could not turn out of this country if you tried to; second, the class that has grown up here in this country sometimes to as great an extent as is necessary, and sometimes not, and is still continuing to grow within certain limits. This second class of industries are those which depend upon favorable conditions, and to a great extent that means favorable power conditions, for their continued growth and existence in this country. The third class will be that group of industries which has not yet found a footing in the country; and

*Manager Oldbury Electrochemical Company of Niagara Falls.

we will also include in that class those industries which have not sprung into existence anywhere, but which the future will surely produce.

Now, taking the first class, we will find that the first electrochemical industry there and an extremely important one, as electrical engineers in particular know, is one that you could not get out of the country, whatever you did to it, and that is copper refining. I think that we can omit any discussion of this particular industry from our subject tonight without losing anything, because it does not bear on the general principles that I want to talk about. It is here because this is a great copper producing country, and the question of power in copper refining and in certain other allied industries is of such a relatively small nature that it is entirely overshadowed by other conditions, principally transportation conditions and conditions regarding interest on the money that is tied up in the very expensive stuff one is handling and refining. So, though this is perhaps as important a single electrochemical industry as there is, yet the electrochemical portion insofar as that relates to power supply is a very minor factor.

The industries that have sprung up in the country in the last twenty-five years can be grouped again, roughly speaking, in accordance with their size as power consumers. One finds oneself in a somewhat difficult position discussing a lot of these questions at the present moment, because though a couple of years ago it would have been relatively easy to pick an electrochemical product and show the requirements of the country in this particular product as equivalent to so many thousand kilowatts, one cannot do it today, because many of those industries have received considerable stimulation from the conditions now prevailing, perhaps not so much directly a war stimulation as a stimulation which has been due to the general increase in business. And it is a matter that I, for one, would not pretend to decide, how far that increase in demand, and in some cases of production, in these particular industries, should be regarded as something that is bound to show a drooping curve in the next few years. That circumstance will make it necessary for me to give you figures with very great reservation, and not attempt to get close to the actual mark; though, as I say, a couple of years ago one could have given them very much more closely and a good deal more definitely.

We find that perhaps easily first of the single electrochemical industries in point of power requirements, and also in point of value of product, is the aluminum industry. As far as one can make out there are something like 130,000 kilowatts of capacity installed in this country at present for the purpose of making aluminum. Not all of it, however, is in operation, because of conditions, particularly at Niagara Falls, to which I will not refer just now. There are, as far as we can make out, about 60,000 additional kilowatts either being installed at present or contemplated, and this indicates the requirements of the aluminum industry alone in this country as

somewhere between one hundred and two hundred thousand kilowatts. Now, no one, I think, can put a definite and arbitrary limit on the rate of growth of that particular industry. The demands seem to be increasing every year. And those demands are not, to a very great extent, war demands, but the increased demand has also come about by the rapid extension of the general uses of aluminum, as for instance, in the automobile. Its use in the automobile is not only direct, but indirect, and includes the manufacture of certain elements or alloys, which are constituents of the modern high-speed steels and of steels of a nature which enables small, light parts to be used in places demanding great strength in the automobile, where a few years ago a carbon steel of much greater dimensions had to be used.

Next in line, and in point of size, we come to a group of compounds which cannot very easily be separated from one another,—the ferro alloys, including ferro-silicon, ferro-chromium, ferro-molybdenum, and so on. It is a little difficult to put a figure to the power requirements of this class. I think somewhere about 100,000 kilowatts would come near the mark.

The next in size is probably calcium carbide, which may take 30,000 kilowatts or more. The calcium carbide industry is not growing today at the same rate as a few years ago. The use of calcium carbide for illumination is not so great. But, on the other hand, the use of acetylene for welding and so on is increasing, and is today, from an engineering point of view, by far the most important use of calcium carbide.

Artificial abrasives are the next in point of size, and I think some twenty to thirty thousand kilowatts—perhaps a higher figure would be nearer the mark—would represent the necessities of this country in the manufacture of fused alumina and silicon carbide, which constitute the basis of all modern grinder work.

Then we have the electrolytic alkali business, which gives us caustic soda or caustic potash, and chlorine in the form of bleaching powder, liquid chlorine or other chlorine products, for which again perhaps 30,000 kilowatts would be a reasonable figure to take for the requirements of the country.

Then we come down to the manufacture of chlorates, which are used in the match industry, in the textiles, for the manufacture of oxygen, and in certain chemical operations. That might be put as consuming about 10,000 kilowatts. And again, sodium, which, of course, is not much used in its original form, but from which is made sodium peroxide, used in the textile industries as a bleaching agent, and which is still more important as a starting point in the manufacture of sodium cyanide, will take up perhaps 15,000 kilowatts.

Then there are a number of minor articles, such as phosphorus, carbon bisulphide, and other products of the electric furnace or of electrolytic processes which might include one or two thousand kilowatts each. And, of course, if we wanted to go into the really small processes, there are numerous little units working all

over the country on this, that or the other special branch of electrolytic work which may take anywhere from a few kilowatts up to a few hundred.

From the consumptive point of view, then, I have given you the actual position at present of the industries that have grown up in this country in the last twenty-five years and now constitute, as I wish to point out to you very emphatically, the absolutely indispensable source of materials without which we today could not get along.

I do not know how I am going to begin to give you any idea of their indispensability. Starting with aluminum, many of you know as much about its uses as I do. It has come into very large use in a considerable number of ways, and we would not like to get along without it. It forms, at any rate in combination with small amounts of other elements, alloys combining strength with extreme lightness. And those of you who have followed, for instance, the tendencies in automobile construction, are aware of the extent to which the advances in the last few years in the ways of combination of lightness with power and performance have depended upon the use of this material. I have pointed out already the extent to which this material is used in the manufacture of high-grade steels which have become indispensable for mechanical operations, cutting, and so on, and also indispensable to structural purposes where extreme lightness and strength are necessary.

When we come to the ferro alloys, the same remark applies. And in the case of one of them, ferro-silicon, one gets a very good instance of how indispensable the products of the electrochemical industry are. About seventy to seventy-five per cent of all the steel that is made in this country today is made in the basic open-hearth furnace. And all of that steel, in its manufacture, requires the use of ferro-silicon. No ferro-silicon, no open-hearth steel. And with the conditions facing the steel manufacturers in these times, that means a very serious diminution, an extremely serious diminution in the steel output of the country, and on top of that I think I could safely add, an extreme diminution in quality. In other words, the whole of the steel industry of this country is at the present time dependent and, so far as we can see, always will be dependent, until something comes up to replace it, upon the single article—ferro-silicon—made in the electric furnace, by the application of electric power to the simplest and cheapest of all materials, namely, carbon, iron oxide and silica.

The artificial abrasives, again, give you another line on the extreme importance of those industries to the general industries. The automobile, at any rate, gives you an idea of the extent to which modern mechanical operations depend upon the use of grinding wheels. Now, the grinding wheel of the newer or artificial abrasive is a different proposition from the grinding wheel of the natural class in two respects: Firstly, the material is better fitted for the job that it has got to do; and, secondly, being an artificial material,

it is under better control in its manufacture, and it is possible to get a far greater degree of uniformity than in the use of the natural product. It takes rather an academic point of view to make the comparison today, because there is practically no natural abrasive material available here. Before the war, about sixty per cent of the abrasives that were used in this country were artificial abrasives —electric furnace products—the remainder being natural abrasives, chiefly coming from Turkey and Greece. Of course, they come from those sources no longer. So, in a time like this, we are in any case entirely dependent upon the artificial abrasives. But whether that were so or not, it is still the fact that the modern technique of grinding and all that that implies—and you engineers know better than I do what it does imply—would be impossible without the use of the artificial abrasives, which the electric furnace has given to the world. The use of the grinding machine has grown and extended tremendously, and its use as a serious factor in mechanical operations dates from the time when artificial abrasives began to be used.

I do not think I need go into detail in regard to the numerous other products that I ran over. If you get a rough line on the thought that I have just been trying to give prominence to, you will see how, though the aggregate output of the whole electrochemical industry of the country may not, if reduced to figures or anything of that kind, look like a thing that could be regarded as of absolute importance to the country, yet, when you come to examine the indispensability of those products (and what I have said in regard to the products that I have mentioned applies to numerous other products as well, which I have not gone into for considerations of time), it is clear that the electrochemical industries of the country are of extreme importance to practically every one of the basic industries of the country.

I know of no way of illustrating that better than taking an automobile and looking over its construction, looking over the materials employed therein, to find out to what extent those materials, and the application of the methods used in the manufacture of the automobile, depend upon electrochemical products.

The American Electrochemical Society got up an exhibit to indicate this at the last Chemical Industries Exposition in New York, and displayed a list of products used, either in the manufacture of materials used in the automobile or in the tools used, such as high-speed tools for cutting and grinding. And from each of those placards were strung different colored ribbons running to the portions of the automobile in which the particular products were used. And the automobile was a veritable mass of ribbons. You could hardly see the automobile for the ribbons.

Take grinding, for instance; there is hardly a single portion of an automobile from one end of it to the other that has not got to be ground in some form or other. There is not a single bit of steel in the automobile, from ordinary steel stampings and that

kind, that is not dependent upon the electrochemical industry for ferro-silicon. There is not a single one of those parts which have been lightened up so much in the last few years that is not dependent upon the existence and use of ferro-chromium, that is now so widely used. And we could go from one end to another of an automobile and talk the whole evening on it. I was told by a manufacturer at Detroit that the use of the alloy steel alone has reduced the weight of a 4,400-pound automobile to 2,200 pounds, made it infinitely safer and at the same time reduced the cost. That was one of the elements that had permitted of the reduction in cost, which has been such a feature of automobile construction in the last few years.

Again, without the use of the high-speed tool steels, which the products of the electrochemical industries alone permit, without the use of the grinding wheels which the electric furnace has given to the world, a plant which can manufacture and turn out 500 cars a day would only find it possible to turn out a little more than a hundred—possibly not as much as that—with the same outfit and the same men. You will get an idea, therefore, of what the electrochemical industry indirectly has permitted the automobile industry to do in the way of cheapening the cost. And it is safe to say, taking all these things together, and others that I have no time to mention, that if it had not been for the growth of the electrochemical industry in the last fifteen or twenty years, and the application of its products to metallurgy and to the mechanical industries, the automobile, as we know it today, could not possibly have existed.

I will give you one other little illustration: without high-grade ferro-silicon, which is 75 per cent to 95 per cent silicon, it would be impossible to manufacture those high-silicon steels which are now exclusively used for core work in electrical apparatus. I cannot begin to enumerate the results of that application, but one of them can be stated baldly in this fashion, that it has permitted the reduction of losses in static transformers to a point where they are now fifty per cent of what they used to be. That, and that alone, has permitted that reduction. All over the industrial fabric of this country you find these electrochemical products working their way and permitting advances in industry, advances in manufacture, out of all proportion to the importance of those products themselves. And I did not want to begin to approach my actual subject tonight without having said these few words to give you an idea of what is the general importance of the electrochemical industry to the country.

So far, I have left one class out altogether, and that is the class of electrochemical products we do not at present manufacture in this country. And among these, the most important are those involving the fixation of atmospheric nitrogen. Now, the fixation of atmospheric nitrogen is, in short, this: nitrogen exists in the air in an elementary condition. Four-fifths of the atmosphere is nitrogen. But in that form it is of very little industrial value. Be-

fore we can utilize it for industrial or agricultural purposes—and its application is principally an agricultural one—we have to combine it, either with oxygen, the other constituent of the air, or with hydrogen, which we can obtain in various ways, to give us nitrates or ammonia salts, or else with calcium carbide, a product of the electric furnace, to form cyanamide. Now, in those forms the nitrogen becomes a valuable manure.

In 1888, Sir William Crookes, then president of the British Association, pointed out publicly for the first time what a great many scientific men had realized already: that the problem of feeding the world would ultimately come down to a problem of supplying the soil with the fixed nitrogen compounds which the growing plant removed from it. You know perfectly well that you cannot take ground and grow cereals on it for a number of years running without doing something about it. The ground becomes impoverished, loses its nitrogen, and you can either reduce its impoverishment by supplying the fertilizer in the form I have been talking about, or you can supply it indirectly with fertilizer by supplying bacteria to combine nitrogen with the air, for instance, by alternating the cereals with leguminous plants which induce the growth of these nitrifying bacteria.

The production of fixed nitrogen compounds by electrochemical means has grown to a considerable extent, particularly in Norway, in France, in Switzerland to some extent, and also in Germany. Also, I may add, in Canada. But we have never been able to introduce it into this country. We shall have to inquire later on why that is so.

There are, of course, a number of electrochemical products that I have not mentioned, some of which are considerable power consumers. Some are of local interest only. For instance, a great deal is being done today in the application of the electric furnace in the refining of steel and in steel castings. That is a problem that need not detain us very long, because insofar as the refining of steel and the manufacture of special steel alloys in electric furnaces are concerned, it is a problem for the steel manufacturer, and as far as one can make out, in the case of the steel plant, the cost of power is very largely a matter of bookkeeping; a man can make it whatever the exigencies of his business make it necessary that it should be. Perhaps it is just as well for the steel manufacturer that this is the case, because if it be convenient to use electric methods of manufacture he can use them, or if not he can excuse himself by saying that his power cost is altogether prohibitive. That is all right in either case.

In regard to the growth of electric furnace steel for steel casting work, that is again a more or less local matter. That industry can flourish in any center where there is, firstly, a supply of good steel scrap, because with bad steel scrap it isn't usual to make a commercial success of the electric furnace for castings; secondly, the demand for a sufficiently large amount of steel castings to keep

such a plant employed; and, thirdly, such a price for power as is usual in manufacturing centers, which, it seems to be conceded today, is quite low enough to enable a steel casting manufacturer to compete successfully with the older methods of casting steel, and not only to make money out of it, but also to turn out a better and more uniform product. So, that condition being so, it need not detain us.

Now, you will appreciate that the term "electrochemical industries" covers a multitude of extremely diverse things. And the problem that we are undertaking to consider is what the nature of their power requirements is.

Well, they require, with the exceptions that I mentioned first—copper refining and other instances of that class—first, cheap power. Everybody knows that. The extent to which that power must be cheap, of course, varies with the different industries. The relation between the power cost and the total cost may vary from only a few per cent—from fifteen or twenty per cent up to sixty per cent or more. By far the largest single cost item in ferro-silicon manufacture, at least under any conditions existing in this country, is the cost of power. In other cases, the proportion is not so large. However, it is easy to see, by looking at what has happened already, where the limitations come in. Up to the present time, with some small exceptions, you can take it that very little power has been available anywhere in this country under eighteen to twenty dollars a horsepower-year. That price, then, has apparently been sufficient to allow the industries that I have enumerated to grow, either to the extent of the country's demands or to the extent of a considerable portion of them. Of course, in some cases they have been helped by tariff. But in other cases, such as the extremely important one of the nitrogen fixation, the price of power obtainable in this country has not been such as to permit of their introduction to any extent whatever.

Now, today we have a curious situation. There is a demand for a larger quantity of a great many of these electrochemical products, principally the ones that have been the most largely manufactured in this country, than the electrochemical industries can supply. And in spite of the extreme adaptability that those industries has shown, they have found themselves in a position where they could not see, and still cannot see, what they are going to do to supply this country with the important articles which have been enumerated. And the more so, as the demand for those articles seems to be intensively increasing. For example, with business the same, with steel sales the same, the output of electrochemical products going into steel manufacture seems to be increasing. And as everybody looks forward to a gradual increase in the uses of steel and an increase in general manufacturing in this country, it is difficult to see exactly what is going to happen.

Now, what is the nature of the hindrance that is bothering the electrochemical industry in this country at the present time? It is

not so much the price of power, because prices have not been raised to any great extent. It is the fact that enough power is not available anywhere in the country where it can be used—mark, where it can be used—at anything like the prices which are necessary. Now, I should say for those articles that I have enumerated, a price of eighteen to twenty dollars a horsepower-year, three mills a kilowatt hour, is a price which will allow those industries to continue to expand in this country. And power at that price simply is not here. Well, of course, we are met with the objection at once that there is lots of power at that price. You have in your minds the water-powers that are developed and looking for markets away out in the west. And that brings me to a point which is of extreme importance in the consideration of this subject, to which I am going to devote a few minutes, because I know that it is not realized to any great extent among electrical engineers and those who deal in matters relating to power.

The production of electrochemical products and their transportation to the markets that consume them, constitutes, looking at it from one point of view, nothing more nor less than another method of transporting electric power. It is subject to the same kind of limitations. You cannot generate power in one place and transmit it economically to another place a thousand miles away. And just in the same way there is a limitation to the distance to which you can indirectly transport your power in the form of electrochemical products. The distance is in all cases far greater. But the limitation exists. And we must inquire in this respect what the nature of that limitation is, and to what extent it holds.

Well, as a practical matter we find that the water-powers in the northeastern part of the country are fairly well developed, fairly well utilized, with one notorious exception—that the ineptitude of governing bodies, combined with the notorious shortsightedness and sentimentalism of our democracy, has prevented the further development of. And with that single exception—Niagara Falls—the water-powers in the northeastern portion of the country are fairly well developed.

In the southeastern portion of the country there are still remaining a considerable number of undeveloped water-powers, some of them being at present in the process of development, chiefly for the purpose of manufacturing aluminum.

There is very little water-power, of course, in the central regions of the country.

When you get out to the west coast, there is any quantity of it. There is supposed to be something like sixty or seventy per cent of the available water-power of the country in the western portion of the country. Up to the present there has been no tendency on the part of any respectable power company generating power from steam alone to quote rates anything like as low as eighteen or twenty dollars per horsepower-year, and we have got to look in the first place to water power for solution of the problems of the de-

mand of the electrochemical industry. Well, what do we find? We find first of all in the northeastern portion of the country that there is not very much to be had. There is not much left. In the southern part of the country there is some left, and it is being developed as fast as the problems of prohibitive governmental regulation allow it to be. Legal restrictions by federal enactment on water-powers have been such that there practically has been no water-power development in the country for the last seven years, as you all know.

Out in the west, as we are continually being reminded by certain of our friends out there who have more energy than judgment, there is lots of water-power. But when we have been heard calling to the skies in our pain that we do not know what we are going to do, they say, "The answer is easy; come out here. We have got cheaper power than you ever saw in the east. We have got lots of it. We have got everything. This is the great, glorious western coast, which is the coming place." But, as I said before, there is a limit to the distance to which you can transport electric power in the form of electrochemical materials. And it is very easy to evaluate that, simply a matter of figuring up your freight rates on your product and—though this is in most cases of much smaller magnitude—freight on your raw materials.

Now, a short time ago I had occasion to look into such figures involving every single article that was made at Niagara Falls in the way of electrochemical products. And I should have pointed out just now that the whole of the articles that are made in this country that I have given you the list of, with the exception of copper, zinc and steels, which I specifically excepted for various reasons, are made at Niagara Falls. It is not true that the whole of all of them is. But the manufacture began there in every case, and in every case Niagara Falls is either the dominant or a very considerable factor in the manufacture. Why is that? Why is it that one particular spot in the country, one particular locality, has been seized upon for the manufacture of these articles, and that to no very great extent have they spread from there?

The answer is this, that since, as I pointed out, electrochemical articles are articles which are used in other lines of manufacture and do not come into general consumption, their market is necessarily in the manufacturing districts of the country. That is without exception true. Now, those manufacturing districts lie in a region which can be pretty well covered in a five hundred mile radius from Niagara Falls. And if there were a center in the country that I could put my finger on as being possibly a better center from a distributive point of view than Niagara Falls, it would have to be Pittsburgh, or something of that kind, as the center of the steel industry, the mechanical industries, though, on the other hand, the dependence of the textile industry on some of those products would throw a considerable amount of weight toward the New England states. However, whichever way you look at it, the center of the market for these electrochemical prod-

ucts is either somewhere near Pittsburgh or somewhere near Niagara Falls or somewhere near a line between the two.

Now, it is an easy enough thing to take the freight rates on those articles and find out what the transcontinental rate would be, say, from San Francisco to Pittsburgh. And it is easy enough if you know how many kilowatt hours a pound, or kilowatts that is a ton, or whatever you like to put it, are required for the manufacture of each of those articles, and then to evaluate the distance in power costs. And the results are rather interesting.

The results of a three thousand mile haul, say, across the continent are somewhat as follows:

If you take the case of aluminum, which is extremely light for the amount of power it represents, which takes a fairly low freight rate in comparison to power consumption per pound, you find that a three thousand mile haul would be equivalent to perhaps something like twelve dollars per horsepower per year. I want to make myself clear. What I meant is this: By the time that you have paid the freight rate on a ton of aluminum from the west to its market in the east, assuming it is marketed in the east, you have an amount which is equivalent to the amount you would have if you had paid twelve dollars a year horsepower more for your power. Consequently, if we conceded that twenty-dollar power is about what is necessary for making aluminum competitively with Europe in this country, it follows that if we are going to take the all-rail haul from the coast—at any rate until the Panama Canal can show us how we can lay these things down in the east very much cheaper than rail can do it—it follows that aluminum would have to have something like eight-dollar power in the west in order to be able to compete.

We go along from aluminum to all these other articles that I have mentioned here, with the exception of the electrolytic alkali industries —and those fall in a group by themselves—and we find out that they all come pretty close to one another; that is, in the relation of the freight rate to power cost. If one does go to the Pacific coast— and assume again that a twenty-dollar horsepower rate at Niagara Falls is about all those industries will stand—then we find—assuming again that their market is in the east—that in order to establish their manufacture on the western coast for the eastern markets we not only have got not to pay anything at all for our power, but we have got to receive a bonus of from twenty to forty dollars for every horsepower that we consume.

Now you begin to see, with a good many of these products, what difference a thousand-mile rail haul can make. And you have got to remember that in normal times the distance, in freight rates from Keokuk, for instance, to Pittsburgh, or from Keokuk to the Atlantic coast at any rate, may be a good many times that from Norway to the Atlantic coast, in spite of the very much smaller distance, and you begin to realize that distance from one's market

is just as big a factor in the manufacture of electrochemical products as it is in the distribution of electricity.

You find that very much more marked in the one thing that I have specifically excepted, namely, the caustic soda and bleach business,—the electrolytic alkali business. You find there that the differential freight rate works out equivalent to something like three hundred dollars a horsepower-year between the west and the east.

Now you see the results we have arrived at by these calculations. These are first approximations. We have neglected altogether everything connected with raw materials. And, of course, those are important factors in some cases and are to be considered. But as a first approximation this method of calculation gives the story pretty accurately. We have found if you could get power really cheap in the west, or at a considerable distance—I am not specifically concerned with the west any more than I am with the south or anywhere else, simply with the distance from the central market, or industrial center of the country, from your source of manufacture—we find that aluminum could even come from as far as the Pacific coast if it could get eight-dollar power, and IF it could get its raw material and that kind of thing and labor on a par with conditions in the east. It makes much less difference with aluminum than anything else. Then, taking all the other articles that are made at Niagara Falls, they have got to have a forty to sixty-dollar per horsepower-year differential between the west and the east.

In the case of caustic soda, bleaching powder and electrolytic alkali, the differential is enormous, coming to something like three hundred dollars a horsepower-year.

Now, just to show you how accurately this thing works out, taken, as I say, just as a first approximation, see what has happened. The aluminum industry was the first to start with water power from Niagara Falls. And it went first of all to other sections of New York state, and then to the southern states. There are plants in Virginia, I believe, West Virginia, North Carolina—not all operating yet. But that is the tendency. So you see that the aluminum industry can, within certain limits, wander, and does wander, to where power is cheap. Cheap power is of relatively greater importance to it than a really close proximity to the markets.

On the other hand, we find another important industry wandering, and that is wandering for just the opposite reason. That is the caustic soda and bleaching industry. And the reason is that it will wander to any portion of the country where there is a market of sufficient size to justify the establishment of a unit plant, because once that plant gets in there and starts operating successfully, it is protected by its distance from other plants, on account of the freight rate with which they have to contend. In other words, in the electrolytic alkali business what has to be taken care of in location is not so much the actual power cost as that it shall be in a center

of a district that consumes the whole of its product, because long distance transportation, by rail at any rate, is almost out of the question wherever any competitive conditions come in.

The other industries that I have grouped together as having originated at Niagara Falls are still largely there and do not wander to any very considerable extent. Wandering has taken place, and if we trace the course of that wandering we find it not without its lessons also. That wandering has taken place to a considerable extent abroad. It began not exactly as a wandering, but by the installation of a plant designed and built for the purpose of supplying the markets of the United States being built and erected in another country, in Canada, on account of the fact that the price the power could be obtained for there was some sixty per cent of that which was offered on the American side. That is the Cyanamid Company of America, which is located at Niagara Falls, Ontario, using 27,000 horsepower in manufacturing cyanamide, largely for fertilizing purposes and the manufacture of ammonia, and so on. This is not, of course, exactly a wandering, but is a plant with every consideration of market and of tariff—of course, there is no tariff on fertilizing materials; but who can tell that there never will be?—every consideration of that kind prompted the builders of that plant to put it in the United States. Conditions in regard to power compelled them, however, to put it in Canada, and the only fixed nitrogen plant of any consequence in this country is, therefore, at the present time in Canada.

That was a beginning, and that coincided pretty well with the time when restrictive measures began to be put upon the development of power at Niagara Falls, and when as a result of those restrictive measures the competition for business on the part of power producers became practically zero. Prices and conditions of sale began to stiffen, and this tendency has continued ever since. And a scarcity began which has been felt more and more ever since, and has now grown to the extent of a power famine.

The wandering of that company was followed by the wandering of the abrasive companies. The original manufacturers of fused alumina, which constitutes the most important abrasive material we have, set up an abrasive plant, originally 5,000 kilowatts and now, I believe, 15,000 kilowatts, in Canada. The Carborundum Company set up a plant in France of about 7,000 kilowatts, and when, at the beginning of the war, that plant was not available to them, they had to scurry around in Canada and obtained some 10,000 kilowatts there to make up. Practically speaking, the two firms which manufacture the bulk of artificial abrasives conduct their strictly electrochemical activities—that is, the manufacture of their raw abrasive materials—to the extent of at least sixty per cent in Canada, and not more than about thirty per cent in the United States.

The next wandering of the kind was shown by the interests that combine the Union Carbide Company and the Electro-Metallurgical Company—manufacturers of carbide and all the important

ferro alloys—ferro-silicon, ferro-chrome, and so forth—that I have been talking about. In their efforts to expand and keep up with the growing trade of the country they first obtained control of Canadian plants manufacturing the same articles and proceeded to extend their activities in Canada enormously. Recently they have migrated to Norway, also, and they are building a plant of 35,000 kilowatts original capacity, ultimately to be 110,000 kilowatts capacity. How much of that product is destined for this country I do not know, but knowing the difficulties they have in securing power in America at the present time, I consider a certain amount of it is. So that whereas aluminum, on the one hand, and the caustic and bleach business, on the other, have shown tendencies to wander to other parts of the country through different considerations, these important industries I am now talking about have shown wandering tendencies, indeed, but wandering tendencies to other parts of the world. Why? Because nowhere in this country up to the present is power offered them at a price they can afford to pay, in localities where they can afford to use it.

Now let us consider one or two other important points in connection with the nature of the power requirements of the electrochemical industry. Some of the industries, as you have seen, have not been able to get cheap enough power to get even a footing in this country. I don't want to go into the nitrogen question, because it would take the whole evening by itself. But the Cyanamid Company apparently had to get power at about fourteen dollars a horsepower-year. It could not get it in the States at all, and it went to Canada. The arc process, extensively used in Norway, cannot begin to get a look-in in this country. The only thing that is being talked about in that respect is the development of a power of an extraordinary nature on the Saguenay River in Canada, where there is the best part of a million horsepower available and the development can be made extremely cheaply from a hydraulic engineering point of view, and where, if the thing is properly handled, there is no question but that power can be produced for only a few dollars per horsepower-year. Well, if that is done, there can no doubt be a competition with Norwegian activities in the line of producing nitrates by the direct arc combustion of nitrogen and the oxygen of the air. But from the data available, anybody can calculate that unless you get a low price of six or eight dollars per hoursepower-year, you cannot produce fixed nitrogen by the arc process and compete with Chili saltpeter, by-product ammonia, or the other sources of fixed nitrogen in normal times. Of course, there are two sides to that: the price of fixed nitrogen products from natural sources tends to go up, and in time the production of fixed nitrogen compounds with a higher cost of power may become possible. However, the cheapest form of fixed nitrogen at the present time is altogether too dear for use as food fertilizer. A very astute student of the subject, Mr. Peacock, in a paper written a year or two ago, pointed out that at the then prices for fixed nitrogen to the

farmer, it meant sixty cents in nitrogenous fertilizer on the farm to grow a bushel of wheat; and, obviously, it is not going to be a paying proposition if it is going to cost you sixty cents for fertilizer material alone to grow a bushel of wheat when wheat goes down to what we would all like to see it. Mr. Peacock set up the ideal which the fixed nitrogen manufacturers must seek for fixed nitrogen if it is going to be used universally as a fertilizer, as a price something like thirty per cent of the price before the war.

So much in regard to price and price limitations. We have already looked at the limitations of locality,—cheap power is of no use to the electrochemical industry if it is not in a place that has available proper and cheap transportation to the market. The individual illustrations I have given you will show you these limitations are not fanciful, but are really serious ones, and that these transportation limitations are really the reason why the electrochemical industries that I have described have grouped themselves in the east, and have largely grouped around Niagara Falls, and why such wanderings as they have shown have been rather to foreign countries, such foreign countries, at any rate, as could afford them cheap transportation to the Atlantic seaboard of this country, rather than to other portions of this country, such as the south or the west, where water power still exists, but, however, in positions which would involve prohibitive transportation rates for the products.

Now let us look at another point which engineers are very often fond of putting up to us in regard to our claim that power is not available for the electrochemical industries at sufficiently cheap rates. They say—particularly engineers connected with operating electric companies—"You know there is such a thing as off-peak power. Off-peak power is something we would like to get rid of, to sell. We can give you a really nice, cheap price on it, something you never heard of. How do you want it? How much can you use? And do you have to have it more than an hour or two a day, or what?"

Well, in the first place, I have never heard any really cheap rates given for off-peak power. When you get down to what an engineer really means by cheap power it is usually, "Something like fifteen per cent below our regular rates." Now, I am not going to say that there are not electrochemical industries that could not take off-peak power to the advantage of themselves and to the advantage of the power producing companies, but I am going to point out how seldom the case can arise.

What is the theory of this off-peak rate business? We will confine ourselves to steam generation, because hydroelectric generation has no business with off-peak power, anyway; in these days of cheap steam power, you cannot justify its existence. What is the steam power producer trying to do? His plant is earning money part of its time on all of it, and part of its time on some of it. I don't know what his plant cost is, but they tell me in these

days you can build electric power stations from one end to the other at a cost of something like $54 a kilowatt. He has his fixed charges on this investment. And he says to the electrochemical man, "You are just the fellow we want. We will give you service whenever we want you, and cut you off whenever we don't. We will give you a really cheap rate."

And the difficulty comes in when they begin to discuss what they both mean by cheap rates.

The trouble with the whole proposition is this: The central station man is relieving himself of an investment charge of $54 per kilowatt installed. That is, therefore, the most that he can relieve the customer of in regard to power that he sells him off-peak. But what is he asking the customer to do? He is asking him to multiply his own investment by some factor that will vary in different cases, according to the proportion of full time for which he can definitely guarantee to give him power. To that extent, whatever it is, he is asking the electrochemical manufacturer to lay down plant in excess of his normal requirements in investment.

Now, why can't those two get together? The reason is this, that in 99 per cent of the cases that you would select for that kind of an experiment you would find that the additional cost that is required to lay down this excess electrochemical plant would be very much greater than the investment that the central station man theoretically relieves his consumer of. In other words, while he can come to me and say, "I can give you power at a rate in which I will not figure charges on my $54 per kilowatt capacity," he is asking me at the same time to invest a good deal more than $54 for my per kilowatt capacity, in order to enable me to take that power.

Naturally, when I get to figuring the thing out on a perfectly simple arithmetical basis, it works out in the long run that I am going to be considerably worse off than if I take his power at his regular rates. That is a point that I want to emphasize rather strongly, because a case has never yet come to my attention of a central station man and an electrochemical manufacturer trying to get together on this proposition without that particular point coming up and stopping the discussion where it began. And yet it is not a point that is realized by electrical engineers and engineers in general, and I am sorry to say that it is very far from realized even yet by central station men.

So that we have got to put it down that regularity of supply, as well as cheapness and a convenient locality, is also a necessity for the electrochemical manufacturer. I do not say, note that, if you could get a guaranty of power for eighty or ninety, or even seventy-five per cent of the time, there are not electrochemical plants which would not be justified in considering an off-peak power proposition. But the trouble is that contracts are not written that way. When you enter into an agreement of that kind, and draw your contracts and make your investment, you will never find that the power producer is willing to tie himself up for a period

of years to give you power for these particular percentages of the time. You will always find that you put yourself in a position where some day—and it is always going to be the time when you want power worst—he can turn around and say, "You can take it according to contract—that is, as often as we want you to."

Anything of that nature certainly cannot be said to fill the condition of regularity of supply.

Now there is a fourth point, and this is something that, as far as I am aware, has not been considered up to the present by anybody I have ever heard discuss power for electrochemical purposes. Electrochemical industries require power that is not only cheap, in favorable localities, and regular, but of which the supply is elastic. Now that comes about in two ways. First of all, the history of electrochemical industries shows a condition of regular and continuous growth. If they are going on to grow, the growth must be in places where, as demands for power come up, they will be met. Secondly, apart from their growth, they are subject to fluctuations like all other businesses. It is not a very nice thing for an industry that has got to have power cheap as a vital condition to have to tie itself up to a contract which obligates it to take practically all the power that it uses in a boom year for periods of considerable extent, sometimes covering lean years, and to pay in lean years according to its diminished consumption on quantities which make it equivalent to paying a very considerably higher price. And yet that is necessarily always going to be the case, is it not, at some period or other in the development of any hydroelectric project that is able to fulfill the general conditions for supplying the electrochemical industry? You can see that condition very clearly at Niagara Falls. As you know, there has been a power famine there for a considerable period, and it has become very intense. Well, the situation is there now that practically firms get the power they contract for over considerable periods of years, and no further power. And supposing you could turn on more juice tomorrow, up to a limited extent, and go out and sell it to concerns that haven't got enough: those concerns would find themselves in this dilemma: shall they take up this power in order to take care of the business they have this year, and sit up with it for periods when they may not have the business, is it a paying proposition for them?

Now in regard to any other raw materials for the electrochemical industry, and in general in regard to the raw materials for industry, one does not have to tie oneself up so closely. And yet when you come to consider the matter, that is necessarily what is always going to happen in the case of water power which reaches its limit of development, or which reaches, as in the case of Niagara Falls, the limit of the development that is permitted.

Now, what are you going to do? The only way by which you can get elasticity in providing the electrochemical industries with water power is by keeping a certain amount of that water

power idle in bad years. That simply passes the buck to the gentleman who has put his money into the water power project, and he needs very little prompting to point out that he has made a very considerable investment per horsepower, perhaps going up as high as $200—really, there are no average figures for that kind of thing —and "Do you think I am going to have that lying idle? Not at all."

It seems to me what has got to be considered, and what will come up more and more for consideration every year now, is the provision in regard to hydroelectric installations, of steam auxiliaries for use merely as take-ups in times of extraordinary business.

It is true that a few years ago the use of steam auxiliaries in connection with hydroelectric plants supplying electrochemical industries would have been sneered at, and sneered at because it would have been pointed out that electrochemical consumers all grumble too much about the price of power; and that steam power provided in those localities would be used merely as a take-up to look after the seven-year business peaks, or whatever you like to call it. But in the first place I think at least that the present conditions indicate that the consumers would not mind paying an increased price temporarily for that kind of power service, and secondly, conditions in steam generation are such today that it is going to be a question in a good many parts of the country—it is going to be a question even in the Niagara Falls district—as to whether the solution of the whole problem is not going to be in steam.

That brings me to the one point I want to bring up, and that is this: we have reached a point at which there is no apparent salvation for the electrochemical industries in this country, or their growth, insofar as they depend on hydroelectric enterprises. It is not because power cannot be generated, and generated in the localities that are favorable for its use. It is because governmental restrictions in general in regard to the water power sites on navigable streams, and so on and so forth, and, in particular and specifically in regard to the development of the greatest water power asset we have got from an electrochemical point of view—Niagara Falls—have made it impossible to look forward to any considerable assistance from these sources. This is a matter that I personally feel very strongly about. It seems to me a crime against political economics, a crime against conservation, and a crime against the industries of the country, and a crime against progress, to allow water powers that are available, and can economically be used, to go to waste, because of unnecessary restrictions. I do not think that the engineering bodies of this country have done their duty in agitating this question and spreading a proper conception of the importance of water powers from this point of view among the public at large and in the general press. Something has been done. The Institute of Electrical Engineers has at least dropped, to some extent, that aloofness from anything that might savor of touching a political matter which characterized them until the last few years, and have

appointed a water power committee which seems to be trying to do something in the matter. But it is altogether too conservative a committee.

We had a conference with them on this subject prior to the meeting in Washington last April, when they were trying to get some action on the Shields bill on water power development. And they asked our assistance. We said we would be delighted to give it, it was something that we wanted—general assistance in the development of water power would assist the industries, the electrochemical industries more than anything else. Then we turned around and said, "We have got a little trouble of our own. Some of you know we are trying to get through a little relaxation in this Niagara situation. Will you help us?" "Oh, dear, no; that would be like waving a red rag at a bull."

Well, I notice at the same time we have managed to get a temporary release of the 4,400 cubic feet which could still be used under the treaty, with some hope of getting a permanent release of that at Niagara, and I haven't noticed that our conservative friends among the Institute of Electrical Engineers have got the Shields bill through or anything like it. But seriously, these questions are things that engineers cannot sit down and let work themselves. They have got to go down to Washington and get hold of their own representatives, hold local meetings, and talk among themselves about it, write papers, get in the public press whenever they can, write articles for the press, do everything to get it through. They have got to do this. Nobody else will. And, as a matter of fact, engineers not only ought to do these things for themselves, but it is a duty that they owe the lesser educated portions of the community, to tell them what they are doing by listening to rank sentimentalists on questions which are matters of solid calculation and solid economics.

The unfortunate thing, of course, is that hydroelectric development, of Niagara in particular and of the remaining power in the east which might be utilized, is apparently stopped for the present, and, as far as we can see, cannot be started very easily to any extent that is going to give considerable relief. What is going to happen? Is it possible for steam to take its place? The answer of all those who study the matter from this point of view is, to a large extent it is. It seems to be an established fact that with coal at two dollars at a modern steam plant you can have a plant with a capacity of, say, twenty thousand to thirty thousand kilowatts up, and you can safely figure the cost—all items in—of perhaps seventeen to eighteen dollars per horsepower-year at the switchboard.

With coal at \$1.10, which is a condition which can be met with in the coal districts and the mines, there is no reason, apparently, why one should not get the price down as low as fourteen dollars per horsepower-year.

Is this going to be done? We see little tendency for the central station man in districts where coal conditions are favorable to take up these problems and make them their own. And, on the other

hand, it is going to be a little difficult for the electrochemical manufacturer to do it himself, unless he is, first of all, in a business of an enormous scale. Now, you will notice that in the list of industries that I gave you there are only two which are of such a size that the individual constituents of that industry could very well put up power plants of their own of sufficient size to begin to get economical results. That is one thing that is going to limit the use of steam power for this purpose, because, as a rule, the power requirements individually of electrochemical plants are too small. And the second point is this: you cannot apply the same principles of amortization to a chemical plant as you can to a generating station *per se.* Or, in other words, if a large generating company sets up a large plant for the purpose of supplying an industry which is diversified and which does not consist merely of one or two particular lines, it can feel that in regard to amortization and in regard to the ultimate safety of the investment it is pretty much in the same boat as a public service utility company and can figure accordingly. The chemical manufacturer who installs a steam plant for his own purposes cannot figure that at all. He has always to take into consideration the history of chemical manufacturing, which shows in an alarming number of instances an extremely high rate of obsolescence on either processes or products. And I venture to say that in no line of chemical industry, except one or two staple lines and to some extent not even in those, is it safe for a chemical manufacturer who wants to be really prudent and not take undesirable chances to figure on an amortization period for obsolescence of one kind or another of longer than six years.

Undoubtedly it will be done. There is no question in my mind but that some manufacturers will attempt to some extent to meet their requirements from the development of steam power by themselves. As far as we can see at present the requirements of the aluminum industry are for a cheaper power, if possible, than can be obtained today from steam. But the smaller industries are only likely, so far as I can see, to produce steam power on their own initiative in cases where they can economically combine it with their present power contracts for hydroelectric power on their present sites in order to avoid duplication of plant.

However, it seems to me that the field is open for large development, the nature and extent of which it is difficult to forecast, in fields near the coal centers, by which large plants, erected for the purpose of supplying groups of industries such as I have been talking about, could find a growing outlet for their power. As far as I can see, outside of convincing the people of this country and Congress—which seems too much to hope for—of the advisability of encouraging rather than discouraging or preventing the utilization of water power, it is the only thing that is going to put a stop to the tendency that I pointed out, of our electrochemical industries to expatriate themselves to other countries. The result of this expatriation, while it may not be noticeable in normal times, will

unquestionably, if another world crisis occurs such as this and disturbs the usual avenues of communication, result, if that expatriation goes on to any considerable extent, in such a shortage of those materials so essential for the general industries of the country that I can conceive of nothing but industrial chaos resulting under those conditions.

DISCUSSION.

Professor Bauer: I wish to congratulate Mr. Lidbury because of the excellent way in which he has presented this subject. Applied electrochemistry covers an enormous field and Mr. Lidbury has touched upon only a very small phase of it.

Whenever electricity is in motion three effects can be produced, a heating effect, a chemical effect and a magnetic effect. These are the only three effects which the engineer, broadly speaking, uses.

Electricity in motion produces heat. In some electrochemical operations the chemical action is brought about by localizing, by this very convenient way, the heat produced by the electric current. There are electrochemical industries which utilize only the electrolytic action, as for instance, electroplating, plants, storage battery manufacturers in forming the active plates and manufacturers of bleaching liquors, etc. Then there are others which require both the heating effect and the electrolytic effect, as, for instance, in the manufacture of aluminium. The electrolytic action in the production of aluminium takes place at a certain temperature, and the resistance of the bath produces sufficient heat to keep it in a molten state.

Now, Mr. Lidbury has shown that in order to carry on the electrochemical industries on a paying basis they must be localized at a certain point. He has shown this localization to be at Niagara Falls, or in the eastern district. I see no reason why, with proper co-operation, other advantageous locations could not be found. He has also shown that, roughly speaking, about 400,000 kilowatts are used in the industries at that point. Now, I do not know just how many hours a day they run, but let us assume an eight-hour day, and 300 days in the year. I would not be very far off, would I?

Mr. Lidbury: Oh, electrochemical processes such as I have been talking about run day and night, twenty-four hours a day, seven days in the week, fifty-two weeks in a year. That is something you have got to assume from the beginning.

Professor Bauer: Then you simply have to multiply the figures which I have by three. Roughly speaking, about two billion seven hundred million kilowatt hours per year are used. Now, that is enormous. But just use your imagination a little, and consider the great field of electrochemistry. We might wipe out entirely all the industries mentioned, and yet we would have an enormous kilowatt hour capacity consumed in the electrochemical industry. I do not mean by industries that are localized at one location on an enormous scale with a lot of capital invested in them by a few firms. But, let

us look over the whole country. Mr. Lidbury has shown that we cannot at the present time interest the central station man to sell to these large electrochemical industries cheap power. But we can interest him, let us look at the electric vehicle as really a small electrochemical manufacturer. Whenever he charges the storage batteries in that electric vehicle, electrochemical actions are taking place. He is really manufacturing spongy lead, if it is a lead cell, on one plate and lead peroxide on the other. Let us assume about a million electric vehicles in action in the United States for an eight-hour day. Suppose we figure roughly on what that would mean, and figure on the average of, say, forty-four cells per vehicle. That would mean about six billion six hundred million kilowatt hours per year, and the central station man is going after his business. Combine these figures with those of Mr. Lidbury and we can see in a measure the enormous requirement of power if we include all these little industries along with the big ones of electrochemistry.

I really believe that applied electrochemistry from the standpoint as considered this evening by Mr. Lidbury is only in its infancy. We can look backward and see the enormous progress made in the last twenty-five years. Aluminium began to be manufactured in this country about 1892. Is that about the right period, Mr. Lidbury?

Mr. Lidbury: Yes.

Professor Bauer: And so, this applied science of electrochemistry, as I say, is only in its mere infancy. Applied electrochemistry, in spite of the handicaps referred to by Mr. Lidbury, will come more forcibly into its own as time goes on.

Peter Junkersfeld, M. W. S. E.: There were two points, however, in addition to those already discussed particularly, and on which I would dwell very briefly. One is this, that after all the cost of power in many electrochemical industries is not necessarily the controlling feature in selecting a location. Nearness to raw materials—transportation, therefore, of raw materials, and nearness to market or distribution of the finished product. The latter particularly is often a very important feature. In one instance that came under my notice, that was the controlling feature rather than the cost of power. That happened to be chlorine manufacture, in which the cost of distributing the finished product was a very, very large item. A location that was very near to a market or that had very good freight facilities and at or near a large railroad center was a very important item. So, the cost of power is not in all cases—it may be in some—but it is not in all electrochemical industries the controlling feature.

Another item that I noticed particularly is the very large amortization charge which these electrochemical industries must have on their own equipment because of possible rapid advances in the art.

Mr. Lidbury: I said they ought to. I didn't say they did. Some of them don't.

Mr. Junkersfeld: Now, the central station man in making his rates has got to take a good many things into consideration. In the first place he must deal fairly with all classes of customers, and while very often he might like to make a lower rate, and possibly, if it was a purely private enterprise, he would make a lower rate and still make a profit, he might not be able to do so, because he has got to deal fairly with all classes. And again, the public utilities commissions might not approve of his making a lower rate to, for instance, a chemical industry, that he would not make to some other prominent industry having similar conditions of electrical service.

I do not want to take up too much of your time, but while I am on my feet, Mr. Chairman, I would like to say we have with us a man tonight who has honored us with his presence. And, with your permission, I would be glad to introduce him if I may do so.

The gentleman I refer to is a man who might well be called one of the deans of the consulting electrical engineers of the world. He is a man who operated a central station in Brighton, England, as early as 1881. He is a man who has had experience extending over the entire world. Incidentally, his experience has also been applied to some electricity selling methods right here in Chicago. While Dr. Hopkinson was one of the first to suggest an equitable method of rates, it certainly remained for Mr. Arthur Wright to put those into effect. Gentlemen, Mr. Arthur Wright of London, England.

Mr. Arthur Wright: I have had long experience in the ordinary power station work, but on electrochemical matters I have had absolutely none.

I will, however, make one remark which rather confirms what Mr. Junkersfeld says about the necessity of the finished product being near some market, as I was connected many years ago with that big power scheme at Victoria Falls, on the Zambesi, where at a certain time of the year there are two or three million horse power running to waste, and at low water there is always about three hundred thousand horse power, where you can get in and obtain concessions for using that. But, unfortunately, it cost something like sixty dollars per ton to deliver anything from that site to the ships. Therefore, whatever price you got for electric power there, it was an impossible proposition as far as any manufactured product that I know of. The cost of freight from those big water powers is very often fatal to using those big schemes.

Now, there is another scheme today—probably you know of it better than I do—that huge waterfall in Labrador, where, I believe, there is a continuous run of over a million horse power right down into the sea. But the freight from that district, and the difficulty of getting there, has made that an impossible proposition.

It just confirms what has been said, that the cost of power is not by any means the main governing feature in these cases.

Mr. Lidbury: Do you mean the Saguenay River power?

Mr. Wright: No, in Labrador. Now, I forget the name of the falls, but it is on the St. Lawrence.

Mr: Lidbury: Yes.

Mr. Wright: But this is very much larger than that. I believe a concession was given to some English financiers just before the war to do it, and they were given seven or eight years to finance it. But the difficulty that arose in getting people to go up into that awful climate, although the water came down to the sea, was so really fatal that nobody considered it.

There is one other feature, and that is the regularity of this power, the enormous amount of water power in the world which suffers from a tremendous variation in the quantity. That of the Victoria Falls, that varies from half a million to any number of million horse power. And, therefore, you must only consider the minimum, unless you can get hold of some process that can be used in those varying quantities.

H. M. St. John, M. W. S. E.: I would like to say a few words from the central station point of view. Mr. Lidbury has made that rather difficult. I am firmly of the opinion that if Mr. Lidbury had chosen some other vocation than the one he did, that of prosecuting attorney would have been an excellent one. At any rate he has brought out a few points that I would like to mention a little more.

In the first place, he spoke of the fact that the market for the electrochemical industries is becoming more intensive, that is, in the industrial regions of the country, even when the products of the industry are not abnormally stimulated, year by year the use of electrochemical products is increasing. And at the same time he has shown to a certain extent that the center of the market for electrochemical industries must be on or near the Atlantic Coast.

It is quite possible that it is now, and for some time may continue to be true, that there will be more of these products used on or near the Atlantic Coast than further west. But at the same time I do not think that anyone in this audience will doubt that the use of the electrochemical products in the middle west—Chicago, for instance, and the other large cities in the middle west—is large and also increasing.

I think that when the central station man and the electrochemical manufacturer have gotten together in the past, or tried to get together, the greatest trouble has been that each of them has been ready for a fight, and that neither one has quite understood the point of view of the other. The electrochemical manufacturer talks about twenty dollars a horsepower year, and the central station man talks about a 6, or 7, or 8 cent rate per kilowatt hour, and the two do not seem to jibe very well.

Mr. Lidbury: Why, no, $20 a horse power year is .3061 cent a kilowatt.

Mr. St. John: Just in that connection, Mr. Lidbury, I would like to have you explain later on just about what the average cost per kilowatt hour of the electrochemical industry of Niagara

Falls is. I find it hard to believe that all the industries, at least, have a 100 per cent load factor three hundred and sixty-five days in the year, and that is what they have to do in order to get down to three mills per kilowatt hour; and in order to get the advertised price per kilowatt hour, based on $20 a horse power year—as Mr. Lawrence Addicks has very well expressed it—to do that a manufacturer has to balance his output on the tip of his nose. If his output is less then he figures his cost in kilowatt hours, per ton output is greater. If he wants to use more power than he has contracted for, his excess power, if he can get it—as quite often he cannot—will be charged at an excess rate. And again his rate goes up.

It is perfectly obvious that the central station method of charging power by the kilowatt hour is more elastic. And Mr. Lidbury has very well brought out the fact that the lack of elasticity is one of the great faults of water power as a source of supply for electrochemical industries.

It seems to me that the subject has not been understood and studied as thoroughly and comprehensively, both from the central station point of view and from the electrochemical manufacturer's point of view, as it should be. I have no desire to attack the subject for the purpose of starting a fight. I would like to act as an intermediary.

Mr. Lidbury has proved, I think, that the country as a whole, and the industries of the country, depend absolutely on the electrochemical industries. He has also come pretty close to proving that the electrochemical industries not only cannot expand, but can hardly continue to exist with their present sources of power supply.

Some two or three years ago Mr. Horry of the Union Carbide Company made a statement of a similar nature, saying that it was perfectly obvious that in the course of a few years it would be necessary for the electrochemical industries to depend for at least part of their power supply, and for increasing the amount of their supply, on power generated from coal. And it has also been shown very well that it is very difficult, if not impossible, for most of the electrochemical industries profitably to generate their own power. So we are going in a circle. The country will go to ruin if we have to get along without the electrochemical products. The electrochemical industries will go to ruin if they can't get the power. And they can't get the power from water power. If they have to have it from coal, they can't afford to generate it themselves. They have to get it from central stations. And they cannot afford to get it from the central station. It is a serious situation.

Mr. Lidbury: That is perfectly true. It is not a laughing matter.

Mr. St. John: I am perfectly well aware it is not a laughing matter. That is just the point I am trying to make, that it is a very serious situation. But it is not half as serious now as it will be in the course of a few years, because these electrochemical industries

are in their infancy, and the needs for the products of those industries are increasing from day to day at an enormous rate.

Since it is a very serious matter it is quite obvious that something has to be done about it. That something cannot be done by one side telling how they have to do it, how cheap they have got to get their power, and the other side saying they cannot sell it cheaper than a certain amount, without going into the matter and analyzing the matter a little more thoroughly, I think, than has been done. I feel that central station men in general do not have an adequate idea of the costs of the electrochemical industries. And I do not think the electrochemical industries are very fond of publishing the various elements of cost which enter into their products. It is a little hard to judge how big a factor the cost of power is, and how it is possible to reach an economic balance. The thing that I have to suggest is that, since the situation is serious, and the two parties chiefly concerned are the various producers of power and the users of power in these particular industries, it is practically essential they should get together. So far as I know, no real action has been taken in an attempt to get them together. It seems to me that action of that kind would be very desirable. That is a mild way of putting it.

Mr. Lidbury: I am going to save some of the points until later. But I think it is desirable that at least one of the points Mr. St. John mentioned should be cleared up before the discussion proceeds any further, as it may lead to further misapprehension, that is in regard to the cost of power and what we mean by that.

Now, Mr. St. John has made an erroneous deduction, and I think he is quite justified in doing so from some of the things I said, because I was not explicit on the subject of cost. Whenever you talk about the cost of power you ought to say very clearly what you mean, and say it several times over, several different ways, and then it will probably be misunderstood.

But the situation is and has been this at Niagara Falls up until quite recently, and to a great extent is so today, that companies do not run on firm power. It is only recently that it has been necessary for companies to consider, as I said before, whether they want to tie themselves up for a greater amount of power than they feel they ought to in that respect. Up to recently there has always been power to spare. So that it is not a question of you paying so much a horse power on your yearly peak. Anyhow, contracts read differently.

They have got as many different contracts at Niagara Falls as they have any other place you could find. But this is a typical one: You pay an average horsepower for the month, taken day by day, figured by your five-minute peak for the day. Well, any competent electric furnace operator, even where your loads would fluctuate considerably unless they were controlled automatically, can get ninety something per cent load factor out of an electric furnace under those conditions, and cases have been known where he has

got considerably over a 100 per cent load factor. Modern automatic regulation is a wonderful thing.

There was a contract once that read in such a way that a skillful electric furnace superintendent, by adding a time contact to his automatic electrode regulating device, lowered the demand to 60 per cent of normal every two and a half minutes! A power contract that is drawn so beautifully cleverly may be a thing that you can drive a cart and horses through if you only sit down and look at it once or twice. However, business is not done in that way. As a matter of fact, you can take it that an operator ought to get on a peak contract with decent modern regulating apparatus and decent operation something like 95 per cent load factor, so that under the conditions under which we have been operating, the conditions that I am talking about, $20 a horse power year, comes pretty close to being .3061 cent per kilowatt.

Mr. St. John: Just one more point in connection with off-peak power. It occurred to me Mr. Lidbury was under a misapprehension on that point. In this part of the world off-peak power means twenty-four hours a day, eight months in the year, and nineteen and a half to twenty hours a day the other four months. It does not mean that you are in danger of being cut off at any time of day or any time of year. It is a perfectly definite proposition and paid for on that basis.

Also, I think central station companies often fail to realize, or at least in figuring both sides fail to realize just what a 95 per cent load factor three hundred and sixty-five days in the year means. And a good many times, if the central station rate was actually figured on that basis, while I do not say it would come down to $20 a horse power year, still it would come a great deal closer to it than a great many figures you see.

Mr. Lidbury: I am not referring to yearly load factor. The figures are recorded daily. The daily peaks are recorded and averaged during the month, so that as long as you have a margin of surplus power there is not any necessity for you to maintain your day by day load in the way you describe—to balance your business on the tip of your nose.

Mr. St. John: Of course, you no longer have the surplus power.

Mr. Lidbury: No, we are getting where we don't. That is what hurts.

Mr. Dean: The supply of nitrogen, for instance, is running short. In the discussion of the Shield's Bill last winter it was stated that the supply would not last beyond 1923. That is only six years now—sometime between now and 1923, or allowing a large margin, 1930, we in the United States must find some means of getting nitrogen or we are going to starve to death. That is just plain facts. We are getting a certain amount of nitrogen from the by-products coke industry. But again, the nitrogen coming from this source is dependent upon the coal supply, which is again becoming exhausted.

And the price of coal is going up and will continue to go up to such a point that we will be forced to develop our water powers. Therefore, I feel that every one of us who are engineers should become active and take advantage of every opportunity to impress on our friends the importance of molding public opinion to the point where we will have an entirely different policy towards the development of our water powers.

Now, there has been developed in this country at the present time, roughly, five million horse power from water powers. The present coal consumption for all purposes is a figure roughly approximating fifty million horse power. All sorts of estimates have been made as to how long our coal supply will last—anything from fifty to a hundred and fifty years. But it does not make any difference if it is five hundred years, the time is coming when that coal has gone and we will be forced to develop our water power.

At the present time we are paying a tax, you might say, in the form of a tariff duty of something like forty million dollars a year on nitrate. A part of that could well be expended by the national government, if you will, to foster the development of water powers. Now, why do we have to have such cheap power for the production of nitrogen? Because the efficiency of the process is so extraordinarily low. It is not fair to assume that the process will remain so indefinitely. Certainly there will be development in that line as well as in other lines of electrochemistry in other industries. The efficiency of the process may rise from an efficiency of four per cent to an efficiency of forty per cent, possibly. I have no doubt in saying that it certainly will improve, as practically every other line of work has improved in which man is interested. There is a balance in Nature which is beyond the control of any man or group of men, which provides for the continuity of the race, and the swings of this balance are too long for us to see, perhaps. But, as the shortage of nitrogen comes on and the shortage of fertilizer from Germany, we must find other means, and we will find other means of solving these difficulties.

Now, we are told that the electrochemical industries are crowded about Niagara Falls because the market is there. Why is the market there? Because the industries are there, because the people are there. Why are they there? The industries are there originally because of the coal supply. And as the coal supply becomes exhausted, as the price of coal goes up, those markets for the electrochemical industries will move westward.

There are other things to which we may pin a little hope. The electrical engineering profession, I think today is prepared to offer transmission at a million volts direct current, with a possibility of transmitting a million kilowatts if you like by direct current, if the electrochemical engineer can find a means of utilizing the energy in this form at the end of the line. These are things that men far up in the profession are dreaming about and thinking about and will solve, so that the matter is not hopeless by any manner of means.

These problems must be studied, and in the next few years—in the next generation or so—this country will certainly suffer a veritable famine, as will the rest of the world, if a solution is not reached.

Mr. Winters: I don't believe I can add anything, except perhaps to get a little clearer in my mind what this off-peak power situation is going to mean in the future. We understand, for instance, the local condition is that you can get off-peak power regularly eight months in the year. The balance of the time, perhaps twenty hours a day. I take it that that condition is brought about by the use of central station power for lighting. In the cities in the East that I know about the ratio of power used for lighting as compared to the industrial uses has gradually changed, so that, instead of the predominating amount of power being used for lighting, it is now being used for mechanical purposes in the industries. It may soon be making the same change here. If an electrical chemistry proposition is started it must have a few years of certainty ahead of it. And if that ratio is changed very rapidly, as it seems the rate will change greatly as time goes on, they may not have that certainty and that off-peak power that we speak of.

Again, another reason seems to be given that we cannot discriminate in favor of the electrochemist in the way of rates, although we appreciate, perhaps, that he needs some little subsidy in that line. Perhaps the only solution of that will be that the power people will have to go into the electrochemical business and make it a subject of bookkeeping. If they cannot produce their power at such rates, or cannot get by the commission with such rates that the electrochemist can buy it, perhaps they can send their power by the method we speak of, transmitted as electrochemical products, thereby getting away with it. But this fact—the real thing I would like to know is whether there is any justification of our belief, or whether there is any justification in believing that there will be power ten years hence in the same ratio, that is, eight months of the year, and the balance of the time twenty hours a day, or not.

E. J. Fowler, M. W. S. E.: In answer to the last speaker I would state that in Chicago about 60 per cent of the output is for street and elevated railway purposes. The proportion would be somewhat the same in any large community. The street railway load is, roughly, 35 per cent higher on account of the heating in winter than in summer. And they also have very decided morning and evening peaks.

Further, looking into the future, steam railway electrification, especially in large centers, will probably have peak and load characteristics similar to the street railway.

The lighting load may not be holding its own compared with the strictly stationary power load. But when you take into consideration the urban transportation, as above, I think we will have a large off-peak capacity for as far ahead as we can see.

At the present time the off-peak capacity in any large community is a very considerable figure. And, coming to Mr. Lidbury's

address, I do not think that the load factor possibilities ought to be limited to 70 or 75 per cent for this off-peak load. Speaking from an intimate knowledge of the load curves throughout the year, off-peak supply of 90 or 95 per cent load factor seems perfectly reasonable to me. I would say, just roughly, in quantities in a community of this size, of possibly 70,000 to 90,000 kilowatts.

And if we can supply off-peak at 90 to 95 per cent load factor, the point Mr. Lidbury made that you balance the investment of the chemical manufacturer against the saving of investment to the power producer is greatly minimized; for if you get up to this load factor I don't think there would be any additional investment to the chemical manufacturer, as I understand it.

I would like to ask Mr. Lidbury one question, and that is, is it practical in most of those processes to operate with power off for three or four hours per day for each day for three or four months of the year? Does that have any serious effect in increasing the cost of operation?

Mr. Lidbury: Why, yes, in nearly all cases. In some cases discontinuous operation is a practical impossibility. In others it is undesirable. In, for instance, electric furnace operation you may take it that a shut-down of two hours would mean in effect a loss of power for an additional two hours on putting the load on again, to say nothing of the disturbance of operating conditions, the effect of which can be hardly evaluated. In a good many processes discontinuous power leads to such a disturbance of conditions that it is quite impossible to operate satisfactorily in that way.

While I am on that point I would like to mention something else in regard to off-peak power. Of course, if the electrochemical industry can get off-peak power that will give it, say, an 80 per cent load factor throughout the year, or something like that, it comes within the realm of things that can be considered, but it must be attached to prices such as I have been talking about, or better. It is no good taking the usual kind of prices in connection with it at all.

Then, each particular instance has to be considered by itself, as to what discontinuity it can stand and what that discontinuity means in additional cost of operation.

And there is a further point to consider. The electrochemical industry taken as a whole has its peaks and valleys too, its seasonal peaks and valleys. Now, its normal peaks are in winter and the normal valleys are in summer, pretty much the same way as the central station business is. And that is one thing that makes water power particularly attractive to the electrochemical industries. You don't care whether you get 25 per cent less in summer as a rule. If you have got to take more power in summer than in winter to fill up your yearly supply you are going to have a big interest cost on the stocks you are carrying. Of course, these things have got to be figured for every particular instance.

Mr. Fowler: We have one contract in Chicago which is essentially an off-peak contract—upwards of 4,000 to 5,000 kilo-

watts—that is practically in continuous operation. The off-peak feature simply specifies that in case of necessity during certain hours it can be cut off, in case of shortage of capacity. In normal years, with normal operating conditions, the capacity is always available because of the reserve which it is always necessary to carry. It is only in case the supplying company is actually so short on capacity because of breakdown or other unusual causes that they have got to save in every possible way that the customer is cut off.

One thing that appeals to me is that our great centers of industry, Chicago, for instance, is 500 miles from Niagara. There is a very large steel production in this community; there must be a considerable use of the product which Mr. Lidbury's company produces and of a great many of the other chemical products in a community where there is such a large amount of manufacturing. Detroit, the center of the automobile industry, is as near Chicago as Niagara. New York and Philadelphia, where an enormous amount of off-peak generating capacity is available, are upwards of 500 miles from Buffalo. And there must be a large use in these centers of all the electrochemicals that are produced at Niagara. The freight rates should work against Niagara, it would seem to me, in the case of the chemical products used in those centers, which would allow, to a certain extent, a somewhat higher cost of power than at Niagara.

Mr. W. E. Williams: Lest what I think to be a vital point may be missed in this discussion, let me say what many, or all of you may know, and that is the sentiment which resulted in the restriction of the use of the water at Niagara was generated largely by a society, the name of which I do not now recall, that advertised widely for money "to save the falls" from the standpoint of patronism and philanthropy.

They gave to many, I think, the idea that the falls were really in danger as if Lake Erie were to be drained out by the power companies. They must have gotten in considerable money from deluded people, as their advertising was extensive for a time, using the best magazines.

No adequate steps seem to have been taken then or since to counteract that sentiment. We get scared over our coal supply and all the time overlook the thousands of tons of it that might be saved by using the water that is running to waste every day over the falls.

I tried to stem that sentiment a little and wrote letters to the officers of that society that was advertising "save Niagara," and called their attention to the loss in our coal beds that might be saved by the full use of the Niagara power.

In return I received some amusing, sassy letters.

I answered that they were worse than Nero who burned Rome for sightseeing purposes only. Rome might easily be rebuilt better than before, but our coal beds can never be replaced.

I told them that in allowing this water to go unused just for

them to look at running to waste was as bad as to burn a forest for people to see the sight.

I talked with people in the city of Niagara Falls about getting out and working to prevent restrictions on the use of the water and found that they were against further use of the water for power purposes. They would rather sell sandwiches and hotel accommodations to visitors than to develop industries around the town. Visitors to the falls talk with the hotel and restaurant people, but not to the people interested in power development, and go away with the slogan, "save the falls to the sightseers and down with the power companies."

In Buffalo, in sound of the chug-chug of a gas engine, I inquired, why not use cheap Niagara power? and was informed that Niagara power was not cheap in Buffalo. That the power company got a Buffalo city franchise for power as a separate company and they bought the power from the companies at Niagara and resold it in Buffalo at the highest prices that would just compete with the other methods of generation.

There seemed to be no friends in Buffalo in favor of more power development at Niagara.

The power companies at Niagara, I think, should get together and spend some money in educating the country of the waste of coal that might be saved by the further use of Niagara, instead of fighting our Sanitary District from using a little of it.

We engineers and everyone who realizes the wickedness of water waste should talk in season and out of season about that matter, and bring about a sentiment that will use the power.

The power users will wander to Canada or Norway, or whereever they can get the power the cheapest, with all other things considered. Perhaps Norway will take over our electrochemical industries until her resources in that direction are occupied.

You know that the Norwegians were wont to put the New York Ice Trust to the bad by bringing ice to New York City as ballast in their ships and underselling the native ice. They did this until Congress put a tariff on ice to save the trust. Perhaps we must resort to a tariff to retain our electrochemical industries.

I think that the power companies should be permitted to sell power somewhat on the same basis as railroads do transportation, at prices that the traffic can live under, measured against what the business can afford to pay for the value of the service, and not on quantity consumed as is now the case.

It would appear that more "off-peak load" power might be secured with safety for electrochemical purposes if some means were used to connect more or less widely separated power systems by high transmission lines, that they might draw from each other and even up the variations in peak loads, and get a higher average of general consumption.

Mr. Fowler: I think that from an economic standpoint the time is very rapidly coming when all these things will be considered,

and when there will be a very large production of electrochemicals in our great centers of population. Off-peak rates are being studied more closely all the time.

Mr. Jones: Someone suggested tonight closer co-operation on this matter of power for these purposes. I would like to say that arrangements are now being made for a joint committee by the Power Sales Bureau, and we are all apt to get in a rut and think we cannot do things because we never have done them. And the older we get the more apt we are to get in the ruts. I believe we are going to find some way out of a great many of our difficulties.

I do believe that it is very important that the water powers throughout the country should be developed to their fullest, because there are millions of tons of coal which are being taken out of the ground every year which ought to be left for posterity.

S. Montgomery: I would like to ask Mr. Lidbury if the Union Carbide Company bought up the Shawinegan Falls plant. I believe the Union Carbide Company's patent expired three or four years ago, their basic patent on the process. For that reason it might have been easily possible for still other rival companies to arise. I was wondering if they had done this in order to insure continuous monopoly after the expiration of their patent.

The question of the scenic effects at Niagara Falls can be solved very easily by running excursions to the Falls one Sunday in a month, and on that particular Sunday closing the head-gates of all the power companies, so that everybody can see the falls on the day that the water is flowing. That would mean the loss of only one day in a month, or possibly do it every other month, or leave out the winter months so that there would be only a few days lost, and those few days could be efficiently used for making repairs and alterations in the power and chemical plants. I think it would be perfectly practicable to arrange so that all the plants operated at the same time and shut down most of their turbines together on a given date.

One of the speakers, in discussing the paper, mentioned the possibility of there being a million electric vehicles in the United States. I think a tenth of a million would be considerably more than actually exists. I do not believe that the total power plant in electric vehicles would amount to anything like the storage batteries used in stationary installations.

In regard to the advantage of locating the chemical plants near the point of consumption, frequently you can offset that by placing them nearer the locality of raw materials. That is particularly true, I think, in the case of the Pittsburgh Reduction Company. They are bringing their ore from Mexico and Georgia. And they are actually carrying that Mexican ore into Quebec for reduction. I cannot see that the long haul across the prairie states would be an economical proposition in the future, because the chances are that even with a vary much higher freight rate on the reduced aluminum produced, the shorter haul of ore to some point in the Rocky Mountain water-power section would counterbalance the excess haul of

the metal and by-products from that point to the market, say, in St. Louis or Chicago.

I would like to ask, also, what the composition is of the high speed tool steels which contain aluminum, and whether the total power consumption for manufacturing the ferrous alloys would rank that product third in power consumption among all chemical products?

I believe that no mention was made of the production of carbons and graphites as one of the principal uses of power.

Mr. Junkersfeld: I would like to call attention to just two points which make for thoroughness and co-operation. I do not refer to the kind of co-operation that means something for the other fellow to do. I mean working together for a common end.

The first point regarding water powers, I agree very fully that every engineer ought to do what he can to urge our government to permit the use of reasonably constant undeveloped water powers, of which there are still a considerable number. It certainly is a crime to allow reasonably constant water powers to go to waste and burn up coal. I would call attention, however, to the fact that there are a considerable number of water powers that it does not yet pay to develop because there is too big a variation between the power available in one season of the year and that of another. You must study them rather carefully. Some will pay development, and some will not pay.

Now, regarding the cost of power from steam stations, I would like to call attention to the fact that the public utility companies are not running a private business, and, therefore, the public utility business is different from the ordinary business and it does not even follow as a practical matter the fundamental laws of business. Practically every manufacturer, every merchandiser, as the costs increase on his materials, can raise the selling price. As a practical matter, the public utility companies, except in very rare instances, cannot do that. They are working against a fixed up-set selling price, and the costs at present are going up very, very rapidly. Their machinery and equipment costs anywhere from 15 to 50 per cent more than two years ago. Their selling prices are practically the same, and in some cases lower.

Furthermore, as I said before, they have got to deal fairly by all classes. They are usually only allowed to make six or seven or eight per cent on the investment. Of course, no manufacturer is going to invest his money unless he is going to make more money than that.

Furthermore, they have got to deal with classes of service to a certain extent. Now, if we take simply the two extremes with an electric company, and say that seven or eight per cent has got to be earned, if the retail rates are forced too low, or too many retail customers are carried at a loss—and nearly every central station in the country does carry a certain number of residence customers at a loss—that loss must be made up by other customers. If all the retail customers paid a good, fair margin of profit, current could be sold

a little cheaper to industries than the usual electric company prices. But that seven or eight per cent is necessary to attract capital and has got to be made out of the customers. In Chicago last summer there were some 29,000 or 30,000 customers whose bills were less than fifty cents a month. You can very easily see that these were carried at a loss. So when rates are made for a central station company all classes of customers must be taken into consideration.

It would be a good thing for the nation, and I hope it can be worked out, to have the electrochemical industries encouraged more and more, because sooner or later they will have to have a certain amount of their power generated by steam. All you gentlemen by working together can understand these things, and you must realize that the public utility rates must be divided fairly as between classes. If you realize that an undue pressure—and the pressure is very great just now all over the country—to reduce the retail rates, and if that goes on too strongly you are working against the electrochemical industries, which is contrary to our national welfare.

Mr. Lidbury: I want, first of all, to set Professor Bauer right on one point, and that is that ferro alloys do not require any specific electrolytic action in their manufacture.

Now, the first contributor to the discussion with whom I must deal, as I think, is Mr. Junkersfeld. Mr. Junkersfeld was not present when I described the relation between transportation cost, particularly on finished material, and power cost. And I had shown by analysis of the industries at present at Niagara Falls that if you neglect everything else, such as the cost of transporting your raw materials, and simply deal with the cost of transportation to market your finished product, that that in itself imposes a serious limitation on the availability of power and that in this respect these products could be divided into three classes:

First, aluminum, which on account of its light weight can be transported over considerable distances at a cost that would not exceed the equivalent of a few dollars per horsepower year in its manufacture. And we find that the aluminum industry can move to any point within a reasonable distance of the center of industrial consumption where it can get cheap power. For instance, it is aluminum that is chiefly going to take up the southern water powers now operating and to be developed; and it would not be out of the question, if raw materials were readily available in the West, for aluminum to be manufactured there. But, unfortunately, you have got to add the cost of transporting raw materials there, and that appears to put it out of the question at present.

The second class comprised the rest of the products that were manufactured at Niagara Falls, with the exception of the electrolytic alkali industries, and I showed those might be regarded as having a transportation cost per thousand mile rail haul equivalent to about $20 per horsepower year in the cost of manufacture.

The third group, consisting of the electrolytic alkali products, has such a tremendous cost in transportation compared with the

amount of power required per unit of weight that it can be put almost anywhere in the country irrespective of power costs, provided there is sufficient local market for the output.

That is one point I wish to make particularly clear now, and I wish to congratulate Mr. Junkersfeld on having found it out himself, because he is the first power engineer I ever knew to make that discovery.

Now, a great deal of the discussion this evening has turned around the question of the ordinary central station as a source of supply and of off-peak power. While I have not been here before, the symptoms are much the same as I have met elsewhere, a large amount of energy on the part of the central station representatives in pleading for co-operation and understanding the other fellow's point of view, and a confession also on the part of the central station people that they cannot conduct business along businesslike lines, anyhow. Well, I was, as you appear to have gathered, as Mr. St. John appears to have concluded from my earlier remarks, born a confirmed pessimist. Now, a pessimist is one who declines to follow a line of thought because it is attractive, but confines himself to investigating just what the facts are. And what I attempted to do in dealing with this subject was to point out and emphasize not what we would like, not what we would feel would be the nice thing to do if we could do it, but what circumstances are forcing the electrochemical industries, irrespective of themselves, to do.

Now, these circumstances point most decidedly under present conditions to a wandering of these important electrochemical industries out of the country. There is no getting away from that fact. It is a fact. It is observable. And you can throw statistics around all you like, and analyze your statistics, but, unless your statistics are the kind that will explain that fact, and get to the bottom of it, they are not going to help you. You cannot assume that the electrochemical industry is something that is in this country to stay and grow, no matter what you do to it, that it is something that is immovable, and proceed to figure on its normal expansion as a basis for keeping up some kind of a power rate you would like it to swallow. Nothing of the kind. I regret to say, so far as I can see from the point of view of a pessimistic philosopher in business, that what the electrochemist has got to do in this particular line is simply to stand pat, to simply see who is going to offer him the best power rates in the most favorable location, no matter in what part of the globe or where, and then go there.

Now, you central station people, if you have got the best proposition, bring it out. We will give it favorable consideration. We will even give it a little more favorable consideration than we ought because we would like to save the country if we could, don't you know? But if the country persists in going to the demnition bowwows after all, it isn't our fault, and we decline to cut our throats for the sake of it.

I am afraid there is only too much truth, therefore, in the very

concise set of logical steps that Mr. St. John made up of what I had to say, much better than I was able to say it myself, to the effect that things look very black, and there ain't nothin' to be done, consequently we must do something. I agree with that entirely, except the conclusion. If you or I were going to sit down and figure what to do, there is simply one answer, and that is quick, cheap or inexpensive water power development insofar as water powers can be developed economically in this country. But, as I pointed out, we are not in the least likely to get it, but still that is unquestionably what ought to be done. It is the only safe and satisfactory solution of the whole proposition.

There is, at Niagara Falls, to go back to the particular question, a potential power of something like five million horsepower. There is an available head in the falls itself of two hundred feet and another hundred feet in the lower rapids. But confining ourselves to the main fall, there is a flow of 250,000 cubic feet per second there under a 200-foot head, which gives you 5,000,000 horsepower, at something like 80 per cent efficiency.

The question has been raised as to the maintenance of the scenic beauty and the possibility of turning on of the falls, as it were, once a week. Now, every hydraulic engineer knows that it is absolutely impossible economically to take a large fall and develop it up to the limit. The general consensus of opinion among people who have studied the subject seems to be that if you develop 60 per cent of the total power of the falls you would be doing about all you could reasonably expect to do in an economic manner. In other words, to convert into energy the remaining flow would cost a good deal more than it was worth. What does that mean? That means that possibly 3,000,000 horsepower could be developed there. Divided equally between the two sides, that would be about a million and a half for Canada and a million and a half for this country. Of course, the division at present is not equal. Canada gets 30,000 cubic feet, we get 20,000. That is because you people here very inconsiderately use some 10,000 feet to shoot your sewage down towards the country to help poison the people, so that is reckoned against us when we come in for our share of the water. However, we will assume you won't go on increasing your demands for water for that purpose at that rate, so that we can expect an even deal with Canada in any division in the future. The trouble is, we have got to overcome the inertia of public sentiment that has been manufactured against the utilization of the falls. Of course, that sentiment has not got a single solid inch of logic to stand on. They talk about conserving the falls and about cutting off development to save it. Well, there is a well-known engineer in Niagara Falls, Mr. Harper, who has put the case very clearly in a little pamphlet in which he demonstrates conclusively that there is a natural agency at work that is destroying the beauty of the falls with extreme rapidity. Only five per cent of the water, approximately, goes over the American Fall. The rest of it goes over the Canadian Fall, and the great bulk of it

is concentrated at one particular point, and the erosion is tremendous. The best figures seem to indicate that the recession at this point is more than five feet a year, possibly as much as seven or eight feet. Those of us who have been there ten or fifteen years know that there is a very noticeable difference in the appearance of the fall now from then. The fall does not cover the banks to the same extent as it did. At the edges it is getting thin—its hair is wearing off. And the people throw it up to the power development. Nothing of the kind. It is entirely due to erosion. The flow of the Horseshoe tends to concentrate more and more year by year in this one spot. There is just one way of stopping that, and that is to deflect the water by means of a suitable system of weirs, submerged weirs, or something of that kind, so as to throw it away from those eroded places over the old brink. It is estimated that that could be done very suitably and very nicely with that 40 per cent of the water that no hydraulic engineer would think of using for power purposes. In other words, the only way to save the falls is to stop the water from going over it. If we were to divert 60 per cent and, say, distribute the other 40 per cent over the whole fall, it would be covered better than it is today without any loss in scenic beauty. Nobody who was not looking for it would be able to find a difference there. But with conditions as they are, I am afraid that the only thing that can be done for a number of years is to let things go on the way they are and let the falls spoil themselves from the scenic point of view.

Personally, I agree with the view of the late Mr. Elbert Hubbard. He said he never could see much in the falls anyhow, and as far as he could observe the only people who went to look at them were bridal couples, and they had their minds on something else.

Now, somebody was talking about the interest the power companies had in seeing the development greatly increased. The trouble is the power companies probably don't want to see the development *greatly* increased. They probably prefer to get the water fed to them little by little, a little behind the demand all the time, because that tends to keep the supply behind the demand and to keep prices tight. On the other hand, there seems to be no reason why, after all the experience of the hydraulic development of the falls abroad and elsewhere, developments of enormous size could not be made at Niagara Falls at a very much cheaper rate per horsepower, giving us consequently a very much cheaper price for power than anything we have known in the country up to the present time. And, as I have pointed out, it is unquestionably to the advantage of the country to develop water power extremely cheaply where you can do so and to sell, where possible, at those cheap prices for the encouragemnt of really vital electrochemical industries that we ought to have and do not have, the nitrogen industries. Of course, there is a time coming, as has been pointed out, when nitrogen fixation efficiency will be a good deal higher than it is today. And even today there are some nitrogen processes that, with power not very much dearer than we

have got it in this country at the present, could find a field. It is not only the scenic beauty faddists that we have trouble with in regard to water power development, and I do not think it is correct today to regard them as being the worst. The worst thing we have got to contend with—and this does not apply only to Niagara Falls, but to other hydroelectric situations—is quite a different one, a difficulty that is more insidious, more difficult to overcome, and equally fatal, and that is the attitude of the so-called conservationists.

Now, a conservationist appears to be a person who believes that you can conserve water power by not utilizing it. The particular feature that the conservationist activities voice more strongly than anything else today is the principle of compensation. The principle of compensation is this, you may own land and have apple trees and that kind of thing on it. You can grow your apples and pick them, and you are not taxed for picking them, unless you become wealthy and get $3,000 a year by so doing. But there is no specific tax on picking apples. You may have a stream pass through your land, and go fishing, and you don't get taxed for the fish you catch. But, if you happen to have a waterfall on the stream flowing through your land, why, that belongs to the people, and if you are going to develop that water power and utilize it you must pay to the people of the United States what you rob them of, particularly as if you own water power you are probably a member of the water power trust and damned, anyhow.

Look at the result. Not every water power can be economically developed, and, anyway, the dearer you make water power the less likelihood there is of its being developed, since the only justification for the use of water power, except that it tends to conserve the coal supply, is that it shall be cheaper than power that you can get with steam. Anyhow, you are not going to conserve the coal supply by utilizing water power if it is going to cost more than steam. And from every other point of view, taxation of water power is damnable because it tends to restrict the use of water power, and because it tends to make water power dear.

Now, that is one feature of governmental intervention that has got to be looked after. But there is another that keeps cropping out now and again. We have had it crop out sporadically in the case of Niagara Falls by way of legislative action on that, and you can see it cropping out in the general power business. And that is this: the idea that Congressmen appear to have that proper thing to do is to allow the generation of water power subject to the prior right for the use of that power to municipalities and street railways and similar purposes; in other words, for heat, light and transportation for the great people. Well, of all of the silly things that a man could get in his head, the idea of tying up a power proposition of the most costly type where your per horsepower investment is perhaps seven times that of the per horsepower investment in steam to precisely those loads of the lowest load factor known, is perhaps the silliest.

When I reflect upon all these things naturally I become pessi-

mistic. I see these industries tending to flock out of the country. I see unquestionably quite clearly what ought to be done. And I see there is no chance of doing it. I note with much interest the attitude of energetic optimism of my central station friends, but for consolation I turn to Mr. Dean's remarks: "There is a balance in Nature which provides for the maintenance of the race." That is a nice philosophic point of view to take, and I hereby adopt it. It saves a lot of trouble, because if we find that the country goes to the dogs for lack of electrochemical industries, it is because the race is not fit to survive on account of its stupidity in not using its water power.

Of course, as my friend on the right said, if you put a sufficient tariff on all electrochemical products in this country they will stay irrespective of power cost. I am a great believer in a protective tariff, but you don't need a protective tariff when you can get the identical thing by action in another political direction. Here you have the electrochemical industries of this country. Taking them by and large, they need a certain amount of protection. But what they need primarily is a cheap, sufficient, abundant supply of water power. That is the proper political solution of the whole thing. The second political solution is, of course, to keep them here by means of a tariff. And the third is to let them go out of the country, and when the next mess comes, you will know about it, and you will know about it in a way none of you can realize unless you know the ramifications of the industrial paths in which the electrochemical products go.

I was asked about the composition of high speed tools, if they contain aluminum. They do not contain aluminum. I must have expressed myself clumsily. What I meant to say was that ferro chromium can be made either by the reduction of chrome iron ore or by the thermite process in which they are made electrochemically, though indirectly, through the use of aluminum.

Just one other correction I have got to make. Professor Bauer called attention to this. He said I figured up about 400,000 kilowatts for the electrochemical industries I mentioned. That is not what these electrochemical industries of the country use at their capacity *in* this country. That is what I estimate as being about the present requirements of the country, expressed in kilowatts for these electrochemical products. We haven't got that much capacity in the country. A good deal of it is in Canada, and Canada is one of the first countries to take our basic electrochemical industries away from us. It may make no difference, or it may make a difference some day if they are here or if they are located on the Canadian side of the border; but they are going very fast into Canada. They would prefer to stay on this side, but it depends on nothing else than the development of a more liberal policy in regard to the development of water powers, such as the Canadian government has adopted.

THE MAKING OF RATES AFTER VALUATION

By William J. Norton. Presented February 26, 1917.

In working up a paper on this subject I found myself almost unconsciously working it out in the shape of a criticism of commission regulation. I want it understood that such criticism as you may find in the paper is friendly criticism. I am a strong believer, personally, in state regulation; I always have been, and yet as I have worked over our rate regulations in the last seven or eight years it seems to me that the commissions have not used the facilities which they have at hand to the fullest advantage. Those of us who are very close to the problem of rate regulation, unfortunately are not the ones to mould public opinion. We are, perhaps, too close to the problem. A good many consider that we are too involved in the problem and it really devolves upon the engineers who are not so intimately connected with rate regulation to spread any suggestions that we can offer and to help educate the general public into a better and perhaps fairer attitude toward the utilities.

Now, when we take up the subject of regulation, of rate regulation, and go into the papers and books that are written upon the subject, we find that these books deal almost entirely with the valuation problem, and when we go over the work of the commissions we find that they themselves are devoting almost all of their attention to valuations. The result of that is, in my opinion, that the other elements of rate making have been somewhat neglected and I believe that the engineers on the commission can afford,—can well afford to give less attention to the valuation end of the rate problem and give more attention to the other items.

It seems to me tonight that probably the best way to treat this subject (because most of us who are in the rate problems are frequently on the witness stand and occasionally what we say is picked up and an enterprising lawyer on the other side tries to turn it against us), it seems to me that it is a subject that had better be treated rather informally. If what I have to say appears to be a criticism of regulation, or of state regulation, I think I can burden you toward the end of what I have to say with enough facts to convince you that I am for regulation, and it seems to me a good place to close by telling you a few of my ideas as to why I think state regulation is preferable.

I just want to call your attention to the various things that enter into a rate case:

1. Valuation.
2. Rate of Return.
3. Current Operating Expense.
4. Deferred Operating Expense.
5. Operating Revenue.

For the purpose of this paper I shall assume that a formal complaint has been made to a commission as to the rates of an electric utility, and following the usual procedure, that a complete

valuation has been made by the company, and also an independent valuation made by the commission and by the city, and that all of the facts have been presented to the commission, and after due consideration the commission has finally fixed a certain amount as the proper rate making value of the utility.

In other words, we start off with *one* of the following five elements of a rate case determined, namely, *the value of the property*. The other elements which must be decided are as follows:

2. The fair corporate return to which the utility is entitled. This requires a determination, on the part of the commission, of a fair rate of return, which when applied to the value found gives the proper corporate return.

3. The determination of a proper annual amount for current operating expenses.

4. The determination of the proper amount for deferred operating expenses or depreciation.

The sum of the fair return, the current operating expenses and the deferred operating expenses, will give the total revenue which it is proper for the company to earn.

5. The existing revenue of the company must then be studied and established, and if it exceeds the proper revenue, as determined above, a reduction must be made in the rates to the extent of such excess.

In an electric case we now come to the real problem involved, for, having determined the amount of reduction, the question to be solved is in what part of the schedule the reduction should fall.

As we look over our cases before commissions we find that, as a rule, practically all of the money and time in such an investigation is spent in the determination of the value, and little or no attention is paid to the other four items, and the reduction is made in an arbitrary manner without any real study as to the results obtained under each rate in the schedule.

You know in case after case the testimony relating to values occupies months and months and years and years and both sides are worn out and they want to get it over with and they want to compromise or settle in some way, and after all the money and time is spent on the valuation proposition we see the commission jumping directly from the valuation to a settlement of the case, and, as a matter of practice, many of our cases have been settled as a result of actual trading at that point and, as a matter of theory, the trading could have been done from the beginning with nearly as much effect and certainty without the expense of making the valuation.

This looks like a very broad and more or less unfriendly criticism, but as the cases are constituted, especially the ordinary cases of the commission, we find them jumping at a conclusion and getting a certain result in that particular rate case and then they are afraid later on to change the rate of return that they laid down in the earliest cases. Now, it is my opinion that some of the commissions would have been better off if they had simply traded without any valuation and

without committing themselves as to the rate of return. As I stated before, the company has no records by which the commission can give six, or six and a half, or eight per cent, and sometimes we spend days in explaining why a higher rate of return would benefit the public and the company, but, as a rule, all such testimony has been absolutely discounted, the companies have gotten no result from explaining their position in the matter, and after it is all over the commissions do just exactly what they please.

Now, the right of the commissions to decide what a fair rate of return should be is probably the biggest and greatest responsibility that they have, and I have searched through the decisions and talked with the commissioners and I have pretty generally failed to find any real appreciation of this enormous responsibility which they have, and which they have, in my opinion, failed to use properly.

The purpose of this paper is to bring out, as far as may be possible, the relative importance of each step in a proper rate making procedure, and especially to call attention to the neglect that has settled upon all of the elements except the valuation.

Indeed, it is a pertinent question as to whether or not if a part, and indeed perhaps the greater part, of the time and money so spent could not be better used on some of the other items, rather than, as now is the practice, to spend it almost entirely on the first item, the valuation.

The commissions assume that the valuations, generaly made on the reproduction new basis, are absolutely necessary to sustain a decision, because all of our rate precedents come from court cases, arising in general under the fourteenth amendment, where the question of confiscation of the property is the only question involved. The court cannot decide whether this property, or the fair profits of the same, is being confiscated unless it knows the value of the property. The commissions, however, under the public utility laws, are not necessarily concerned with property, but have broad regulatory powers, and under them are fundamentally burdened, in the interests of the public, with the broad question of obtaining the best and most complete service at *the rates which will best accomplish this result.* This is entirely different from the usual assumption made by the commissions that it is their duty to secure the lowest possible rate for the small user.

It is not surprising, therefore, that the commissions have not been as successful as they should have been in the handling of rate cases, because they have failed to understand their broadest duties, and to a large extent have failed to use all of the tools which have been given them, but have insisted upon using the one tool, the valuation, to the practical exclusion of all others, and of using it so extravagantly that they have been forced to jump to hasty and arbitrary conclusions as to rates.

It may pay us at this point to briefly consider the other tools

which the commissions have at hand and generally fail to use properly.

Perhaps the most significant of these is the right of the commission to decide the rate of return to which a utility is entitled. This is a tool which they use, but use so clumsily and carelessly that they would be better off if they did not use it at all. The companies under regulation, as a rule, cannot bring to bear upon the commissions any facts regarding the rate of return which are not promptly discounted by the commission. Usually in its first decision a commission spends so much time on the valuation that it has no time left for a proper consideration of the rate of return. If the valuation comes out higher than they expected, a rate of return is automatically reduced. If the valuation comes out lower than is expected, they are inclined to be more liberal with the rate of return, provided that a certain amount of reduction in rates is still possible. In my opinion the arbitrary power of the commissions to decide what is a fair rate of return is the most important and far-reaching tool that they have at their command. It certainly should never be used to obtain a temporary result in the way of rate reduction. Its largest use in the hands of an intelligent commission should be to build up, in their own state, the possibility of the broadest and most comprehensive service that is possible.

Some of the commissions have used this rule properly, notably California and Maryland. California considers that an eight per cent return should bring into the state all of the money that is necessary for the development of its utilities, and Maryland has also advocated such a rate of return. On the other hand, we have in our own state of Illinois a commission which says that 7¼ per cent is a sufficient return, and the neighboring state of Indiana is convinced that seven per cent is sufficient. In the long run, when regulation is better understood by investors, we may expect to see money flow into California and Maryland, and a disinclination to invest in Illinois or Indiana, with a result that service will deteriorate and extensions and improvements cannot be financed.

They have almost implied that if 8 per cent won't bring the right rate into California, they will make a higher rate. Maryland has decided the same thing, and still it hasn't quite as high a rate, but it is very liberal. On the other hand, in our own state of Illinois we find a commission which has established the rate of 7¼ per cent and it has consistently stuck to that as a fair rate of return, and in the neighboring state of Indiana we have an even worse situation, where they think 7 per cent is a sufficient rate of return.

In determining proper operating expenses, the general commission practice is to make a simple audit of the operating expenses. Occasionally some obvious over-expenditure may be thrown out, but no attempt has been made on the part of any commission to make a real study of the efficiencies and economies of operation, or, on the other hand, to determine if waste or extravagance has prevailed. Up to this time there has been no difference in the treat-

ment of operating expenses between the best and most efficient company and the worst. There is no doubt that much time could be profitably spent by the commissions in studying this problem, perhaps the largest and most important problem that confronts them. The commissions have the right under the law to require annual reports, and these reports could be improved so that the relative efficiency and economy of the operation of every like company under its jurisdiction could be determined. This has not been done. Why? As a matter of practice, we find the commissions use antiquated forms of annual reports copied from one commission to another, or from the interstate commerce reports. No study is made of a useful or proper form, and while they take a great deal of time to prepare on the part of the company, they are rarely used except for practically worthless statistics printed in a voluminous annual report, which is read by no one.

I think I speak advisedly. I have seen storerooms filled with reports that it took the company months to prepare and the only worry in regard to them was for some file clerk, as to what he should do with them. If they cannot be used for constructive purposes the commission ought not to ask for them.

The annual and other statistical reports of the commissions should be required only when there is a definite use for such data. They should be carefully and thoughtfully worked out, and when received, should be used for a constructive purpose. Here the commissions have a real tool which is practically unused.

In a rate case it is obvious that the actual operating expenses of the company should be studied with great care and with particular reference to the efficiency and economy which has been exercised.

Now this is a very big problem. Most of the engineers and lawyers in presenting their pleadings have been very careful not to bring up this point. They generally felt that there was hardly a commission in the country, probably outside of the old Wisconsin commission, that really understood the subject well enough to thoroughly appreciate what operating expenses really meant and what they stood for. The result has been that as the commissions have done nothing about the operating expenses, the companies have been satisfied to leave well enough alone and they themselves have not brought up the subject; but it is right on this particular point that in future rate making, if we make any progress, great good can come.

The problem is involved. Probably everyone who has been in any way connected with rate regulation or rate making has established in his own mind that eventually there must be developed some method of rewarding efficiency, and, as a corollary, punishing inefficiency,—penalizing inefficiency. But nothing has been done. I remember talking to one of the Wisconsin commissioners several years ago and he pleaded that there was great pressure upon a commission to do other things and do their routine work and grind

through their cases on the old valuation return. There are so many conditions to be deducted from the revenue theory and take up so much of their time that, while they appreciate something must be done to reward efficiency, they have really no time to take up such a complicated subject. But some engineer, some day, will make himself famous by getting into the operating expense of our utility companies and devising a workable plan whereby efficiency can be properly rewarded.

There are probably greater possibilities in development along these lines in connection with the regulation of utility rates in the future than in any other part of the complete rate study. In New England and in Massachusetts the attempt has been made to reward efficiency of operation by the so-called sliding scale method, but this is a crude attempt to fix a ratio between rates and dividends, which, while it has to a certain extent been beneficial, has not been entirely satisfactory on account of the arbitrary nature of the relation.

Under the fourth item, that of deferred operating expense or depreciation, very little has been actually accomplished, and necessarily so because the oldest of the purely regulatory commissions are but eight years old, and as the theoretical average life of an electric light plant is not less than sixteen years, none of the commissions has had the opportunity of making a study of a complete cycle in the life of such a utility. The preparation, however, of the necessary data for a complete study of depreciation, especially in its relation to maintenance, should be made by every commission, and in another ten years there will be no excuse for a lack of complete data on this subject.

A study of the existing revenues of an electric utility has been made in many cases, but nowhere do we find a complete and thorough analysis of the revenue from the various classes of business, and for the different size customers under each class, that we should expect to find, in a decision which attempts to spread, over all of the revenue, a certain reduction.

Nor do we find in the commission decisions any careful study of the average rate, which is received by customers of the various sizes, under the different rates in the schedule. The attention of the commissions seems to be directed entirely to the maximum rate of the small users, and their studies are made almost entirely for the benefit of this class, so that it is not surprising to find that this is the only class which receives the benefit of the commission reductions, and adjustments in rates for other users are left entirely to the voluntary and practically unregulated action of the companies themselves.

There is no doubt that all rates must be carefully studied before an intelligent deduction can be spread over the schedule.

I must admit at this point that this paper seems to take a rather pessimistic view of regulation by commissions of the rates of electric companies, and the question naturally arises, if regulation has

been so uncomplete, how is it that under regulation the electric utilities have not suffered? The answer is a simple one. No utility has grown with anything like the rapidity of the electric utility. Not only do we find new methods for the application of electric current almost every day, but the old uses of electricity are constantly enlarging so that the gross revenues of all of the electric companies are today building up very rapidly. By scientific rate making we can greatly encourage and facilitate this growth, but the forces behind this expansion are so powerful that even bad rate making is not able to stop it.

There is one point, however, that seems practically certain, although it can only be suggested without positive proof, namely, that a company with high unscientific rates under the present method of commission regulation is probably safer from drastic rate reduction in the hands of the commission than an energetic and progressive company whose rates are particularly low. The present plan of the regulation by drastic valuation, and without any consideration of the economy and efficiency of operation, is apt to hit hardest the most enterprising company. I think I can show that more plainly by the following tabulation, which appeared in an editorial of the *Electrical World* some time ago:

	Value	Fair Return	Rate of Return	Net Corporate Income	Rate Reduction
1.	$100,000	$8,000	8	$10,000	$2,000
2.	100,000	8,000	9	10,000	1,000
3.	100,000	8,000	9½	10,000	500

They assumed that a utility had been valued by a commission and in order to make the problem simple we will assume that the value found was one hundred thousand dollars. The commission also fixed a rate of return and it must have been one of the fair commissions, because the rate of return was fixed at 8 per cent, which meant that the company was properly allowed a corporate income of eight thousand dollars. Then the commission went ahead and studied the existing income and found that that was ten thousand dollars, and the result of the usual procedure was that they ordered a reduction of two thousand dollars. Under the ordinary method of commission regulation, a reduction of $2,000 would be made, and generally this would be handed to the smaller users who were probably the least entitled to such a reduction. Here the commission generally stops, but let us for the moment assume continuous regulation each year.

Now, that is the usual procedure that we go through in a rate case. The editorial in the *World* went on to assume that the commission made such a decision one year, but this was an energetic, though small company, and it did what most companies do when its rates were reduced and its revenue reduced; it speeded up and went after new business and went after increased use of existing businesses and at the end of the year (and again to make the prob-

lem simple, we will assume that there were no additions to the property)—at the end of the year the value was $100,000 and the income had again raised to $10,000.

Now, that may seem impossible, but, as a matter of actual practice, that is what generally occurs in our large development of the electrical utilities. The ordinary commission would again deduct for the second year $2,000, but let us assume, for the sake of fairness, that the commission would come along and say, "Well, you got your $10,000 back, but we have watched your plant and you have done wonders and we believe that it is a fair proposition to increase your rate of return and we will split the difference; we will give 50 per cent of the rate of reduction back to the public and we will let you keep $1,000."

Well, that would mean a 9 per cent rate of return and they would be allowed to make $9,000, and the reduction would be $1,000.

Now, it isn't impossible to assume that situation went on for still another year, and the third year we find our company with a $100,000 value again returning $10,000, and if the commission was committed to a fifty-fifty policy, we will find a 9½ per cent return and a reduction of $500.

Now, that seems to be, certainly, a more liberal ultimate decision than we should expect from the average commission today, but as it goes along, point by point, it seems fair and reasonable.

Now, suppose that instead of the commission regulating in every instance the company itself had voluntarily made the first two reductions, and we come, the third year, to a regulation by the commission on a complaint. Of course, no one had any doubt as to what would happen there. There would be no consideration of the $500 under the present methods of regulation, but the commission would take off the two thousand dollars, and this is actually the situation that confronts many a company the first time that it is under regulation, and it would have been much better off to have allowed its high rates to stand to be deducted by the commission rather than to voluntarily reduce its rates.

Now, the real point in this example is that that is really what has occurred in most companies when they come under regulation. Over a period of years they have made voluntary reductions as their business increased, and they have made big reductions and given them to the public. They come to regulation for the first time, before a commission, and they are placed in a position where, in equity, their rights only ought to be reduced by $500, but the commissions arbitrarily, under their rule, will deduct $2,000.

There isn't a single incentive, under existing state regulation, for any efficiency, any economy, any hustling, to make up for the reductions to the public, and if this company had simply maintained its rates from the beginning and rested on its oars for the three years, they would be much better off than if they, on their own initiative, had made the three reductions.

This brings out clearly to my mind that the methods used by

the commission have heretofore afforded no incentive for progress, efficiency or economy on the part of the companies, and the company that is not progressive is in better shape to stand existing regulation than the company which has energetically pushed its business and voluntarily reduced its rates as its revenues increased.

I think it was Commissioner Moffat, several years ago, who called my attention to another phase in the valuation question for rate making. I pointed out that the companies were very foolish to go through the valuation just before they put in any big unit in their plant or just before they increased their service to any extent. He said, in his opinion, rates should be fixed 10 per cent, plus or minus, if the companies were only clever enough to pick out just the exact moment under which they were to be regulated, and if they were regulated under the existing practice just after they built a new plant and elaborate extensions, they would be 10 per cent better off than if they were regulated just before those extensions were made.

Now, while I have seemed to speak against valuation, I have rather done it purposely because I think everyone else has tended to emphasize the importance of valuations and to neglect the other elements of the rate-making problems.

The commissions seem to forget that under the law regulation is continuous, and both the cities and commissions strive to get the largest possible reduction that can be figured out, and then hand it over to those who have done the least to earn it. If regulation is to be practical and helpful, as it should properly be, our rate reductions will take the form of frequent small reductions applied throughout the entire schedule, so as not to seriously impair the revenue from any class of business, and the companies themselves will be encouraged to make such reductions voluntarily, and if they do, they will receive as much credit, and in all fairness they should receive more credit than if the rates were reduced by the commission itself upon complaint. What we need is constructive and not destructive regulation, so if regulation heretofore has not been destructive in the large part, it is the result of luck rather than of any good intention on the part of the commissions, in that errors that have been made have been covered up by the rapid growth of the business.

This will probably continue to be the case with the electric companies, but on the other hand, we find that the gas companies and the water companies are reaching a breaking point where the arbitrary methods used by the commissions will no longer work, and unless a change is quickly made in the method of regulating such companies, by the assumption that rates can always be revised downward, we may expect to see such cases carried to the courts upon the theory of confiscation, but even this relief is far from satisfactory, as there is a wide margin between confiscation and fair regulation, which the commissions should recognize, and through which adequate service, requiring as it does a large annual invest-

ment for improvements and extensions, can only be safeguarded.

There is one other phase of the present reproduction new valuation basis used by the commissions, which is brought out by the present increased cost of material. It has just been called to my attention in a valuation made and fixed by a certain commission in the latter part of 1916, where the company endeavored unsuccessfully to sustain a base price for copper of 19 cents.

Not six months later the engineers of the same commission were allowing in another valuation a 27-cent basis for copper, and this will probably be sustained by the commission, so that one city in the state will have rates based upon a fundamental unit of value, which is 50 per cent higher than in the first city.

In my opinion, no reproduction new valuation can be absolute. Such a valuation should be used, if made by the commissions, only as a *partial* check in determining what rate adjustments should be made.

Valuations may have another use, and one that is generally forgotten. *This is the much disputed Cost Analysis,* and such analyses cannot be made unless the value has been determined and carefully allocated to the various services in which the investment is used. The utmost care must be taken in such allocations, but even where the detail is carefully worked out, elaborate assumptions must be made, and the results obtained are *averages of costs, and not actual cost.*

A single cost analysis, under any condition, no matter how carefully it is made, has no absolute value. It is an indication of cost; it shows the cost curve which is a sort of a zone of reasonable doubt, and one or two of the companies, especially in the West and on the Pacific coast, have attempted to make those analyses and submit them to the commissions. As a matter of fact, the commissions have simply criticised these analyses, and they took up this assumption or that assumption. I know in one case where they made an arbitrary formula of their own and established a direct relationship between the adversity factor and the load factor, which made the whole calculation come out about the way they wanted it, for the purposes they had in mind. On the other hand, if the commissions would only realize that the costs are the same each year with the same conditions, these analyses over a period of years would afford a safe basis, indicating where proper changes in the schedule rates should be made.

Some of the commissions, notably Wisconsin, have made such analyses, but they seem to have failed to understand that the value of any single cost analysis is not absolute.

For instance, in a certain cost analysis made after a detailed valuation, it was actually found that not less than 5,000 opinion assumptions not supported by actual data, had to be made. It is, therefore, obvious that the result obtained cannot in any sense be considered actual cost, and as a matter of fact, it is probable that not

two persons, even if both were skilled in such matters, could have possibly reached the same conclusion.

And here we again come upon another danger of existing commission regulation, because the commissions which have made such cost analyses have assumed that they were absolute.

The cost analysis has a very valuable function, however, in spite of its frequent misuse. If such an analysis is made over a period of years, as has been done by one electric company that I know of, and the same assumptions made from year to year, but improved as more and more data of real reliability were secured, the general trend of the analysis year by year becomes accurate, and the results of such a study as applied to any rate in schedule could be reliably and safely used in determining whether each rate in the schedule needed adjustment.

No commission to my knowledge has had the patience to work a cost analysis out carefully over a period of years and, as a rule, as the results shown by a single analysis are used as an absolute basis for rate reduction, it is the experience of most companies that to present such a cost analysis is an extremely dangerous and ill-advised proceeding.

The commissions, of course, may have some justification in the fact that the rate-making of many electric companies in the past has been as unscientific as their own methods, but of late years we find that the companies are more and more developing a careful compilation of the results obtained under each rate in the schedule, sometimes supported by an annual cost analysis, the combined results of which are of absolute value, and such information is used by the companies whenever rate adjustments are made.

The time will soon come, I hope, when the companies and the commissions will both make a more intelligent use of their valuations, and other data, and then we can expect our rate making to more nearly approach a science, and personally I have always believed that with more scientific and careful rate making will come an even further development of the electric business.

There are just two thoughts that I want to leave with you as to this part of the paper:

The first is that valuation is only a part of rate making. I may be a little prejudiced on the subject, but I feel that it isn't as important a part of rate making as the other items.

The second point is that eventually we must work out in our rate making some reward for efficiency and economy of operation. Our regulation will not be complete and our eventual development of the electrical business under regulation must proceed under or along some such lines for the proper reward for such efficiency.

Now this slide shows the maximum rates for residence lighting in all cities of the United States over 40,000, as of June, 1916. You will find quite a variance in the maximum residence rates, ranging, as you see, from 13 cents down to a little over 5½ cents for the lowest rate companies, with a rated average of 9 cents throughout all

cities in this country. Now we have grouped according to the actual population served to give a fair indication of the total population served at the various rates.

This is a similar slide showing the minimum charge for the same cities, rated in the same manner. You will find that the average of all cities is sixty cents and now the average is a little higher because since June, the Commonwealth Edison Company of Chicago has put in a charge of fifty cents and the general tendency of the cities that have no minimum charge is to, at this time, establish a fair minimum charge, as practically all the commissions have approved of a proper minimum charge.

Now, as I stated earlier this evening, the general tendency of the commissions in the cities, in attacking the rate problem is to talk a maximum rate and consider and think a maximum rate. You very rarely find a commission looking at the rate problem from the standpoint of what, under the rate, the average consumer of a certain class is receiving. What we have attempted here is to pick out a certain residence customer and for a period of one year, and calculate what each one of these customers would have to pay if he lived in these various cities.

Now there is a surprising difference between the maximum rate and the average rate. The most striking instance is that of Detroit where the maximum rate is 13.4 cents. On the other hand the average under this rate in Detroit is 5½ k. w. hour, so that while Detroit has the highest rate, it is one of the lowest average rates of any city in the country.

The residence consumer was picked with these characteristics and the actual bill for a period of one year was figured out under all the rates.

The next slide shows the average for a long hour store user. The highest average rate paid was 11 cents per k. w. hour and the lowest 5½ cents per k. w. hour, whereas the average dropped from 9 cents to practically 8¼ cents, net.

Now we have worked out in the same way the bill for a factory, a typical long hour user and the next slide shows the result of that average.

There we find that while the maximum for such lighting was in the neighborhood of 9 cents, the rate of average for all such customers was very nearly 7 cents, or two cents lower. This was a small printing shop.

And the next slide shows the averages under this rate, where we find that 6½ cents is the average for this class.

In making these statistics, most of the data was collected for the National Electric Light Association, and as a good many of you probably know, the association is about to publish in a regular book form, for the use of its companies, a complete rate book for the cities of a population over 40,000 and this is just a sample page of that rate book, showing in detail the complete rates as they will be published.

Now, inasmuch as I have made some criticism of commissions and their methods of rate regulation, it seemed to me to be rather up to me to go back just a little and square myself on the general subject of rate regulation, especially as the matter of regulation by State Commissions is a subject that is important at this time in the State of Illinois.

Regulation began in 1885 in Massachusetts; when the gas commission was there started in 1885 it was changed to gas and electric light, and regulated practically no development until 1897, when New York and Wisconsin both established laws, the theory of which was based upon the Massachusetts practice, but both Wisconsin and New York laws were better than those of Massachusetts and were founded upon the practice of Massachuetts rather than the actual wording of the laws.

Georgia, in 1907 established a regulation law, and the powers were given to the rate commission but they practically did little with them until three or four years later. Nebraska gave regulation of stocks and bonds of electrical and gas utilities to the railroad commission in 1907, but have not since then increased their jurisdiction. In 1909, two years later, there was comparatively little change. In Oklahoma there was some regulation which is still incomplete.

Michigan gave its rate commission a right to regulate stocks and bonds and rates of electric companies, only. Vermont passed a law in 1909 which started the commission in that state. In 1911 we see that the Pacific Coast came into line, with California, Nevada and Washington. Kansas also came in, with Ohio, Maryland, New Jersey and Connecticut and New Hampshire.

The Ohio law was a more or less defective law, and it was changed in 1913.

There was still more progress in 1912 on the Coast and Oregon, Arizona and New Mexico came in, as well as Rhode Island.

The most fruitful year was 1913, when Illinois, Missouri and Colorado passed a law which became effective in 1914. Wyoming, Montana, North Carolina, West Virginia, Indiana and Pennsylvania and Maine passed a law which became effective in 1914.

There was no development of any note in 1914, and I have no slide for 1916, but I happened to have a map which was prepared in the office and it has been printed, which not only gives the states under regulation, but gives a synopsis of the jurisdiction the various states have. I have brought some of these over with me and if anyone wishes them I will be glad to give them out, after the meeting is over.

Just one word about state and local regulation:- I am a firm believer in state regulation. I believe that state regulation should be maintained in Illinois, and that the state commission should be strengthened, and improved and given complete jurisdiction, and my reasons are not sentimental, but it has always seemed to me that anyone who carefully considered the principles involved in regulation could come to no other conclusion, but that state regulation

was preferable to local regulation, or the so-called Home Rule.

If you first take it up on the mere question of territory covered, —the railroad and express companies are, of course, inter-state, and in fact, some railroads, like the Michigan Central and the Grand Trunk, are international.

Our electric railroad rates are never,—with rare exceptions,— a purely local proposition. Our electric companies are fast outgrowing the local situation. The service of a big, modern generating system spreads over a vast territory and proper regulation of such companies means that it must be controlled by a body with broader powers than any city power can have.

Gas, it is true, is a little more local, but even the gas companies are extending beyond the city limits, to the territory beyond and the limitations of a gas company in a single city are not important.

Even in the case of water, which is municipal generally, the source of the water supply is outside of the city, and telephone, of course, is state or interstate.

Therefore, on the mere matter of territory covered, the utility regulation problem is too big and it is too involved a problem to be handled by any one city, and it is important to know that here in Illinois we are proposing to step,—or some of the people are proposing to step backwards from state regulation at the very time when the railroads are making a great effort, and most railroad economists are realizing that the grouping up or splitting up of the regulation of the railroads, into various commissions is a very serious error, and it is more than likely that in a very few years we will have our railroads entirely under federal jurisdiction, and at a time when the economists are all coming to the point of single jurisdiction for the railroads, here we find in this state, an attempt to step backward for the other utilities.

Now, when we attempt to analyze the functions of regulation, the most important is the subject of competition. In every city in the Union, the matter of competition and the question of necessity are state functions. The experience of regulation, and especially in the states of early regulation, have shown that the cities are not really competent to pass on the question of whether competition is necessary or not, and all authorities agree that the matter of regulation is a matter for the state.

The second item is that of capitalization. The utility corporation itself is a creature of the state. The regulation of its capitalization is a state function, and as I understand it, from some bills that have been proposed, it is even proposed to take that away from the state commission.

Now we come to the question of the matter of rates. That is the most disputed point of all, of course, but when you come to carefully analyze the average state regulation you find that it is a controversy which exists, not between the consumers of the com-

pany, and the company, but it is a controversy which exists between the city and the company.

Now, such a controversy should be settled by arbitration, and to get fair arbitration we must have some board of arbitration that is not one of the parties. As someone once expressed it, it would be just about as fair if all the disputes between capital and labor were arbitrated by a committee composed entirely and appointed by labor, as if our rates, which are fundamentally a controversy between the city and the companies, were to be regulated by the city alone.

In the same way accounting is a proper state function, and one of the great necessities of accountants is to get a proper form of accounts, and uniform statistics we get from our accounts. Now, of course, commissions in the various cities throughout the state, cannot be relied upon to make our accounts uniform, and our statistics would be valueless, so that from all points, accounting is a state function.

The only function which is a city function, is the question of service, and the question of extensions, and yet, in actual experience in such states as Wisconsin, where franchises require service and the regulation of the service, it has been found that most of these rights of the cities held by the cities were never exercised and the real regulation of service, and the real regulation of extensions did not begin until there was a state-wide commission.

Again, we have the question of municipal operation, a much mooted question, and obviously, in any consideration of what is fair and right, the city cannot decide a proper arbitration of such questions, and it is a proper function of the state. As a matter of fact, of course, our state utility law has very proper and fair provision relating to the control of municipal utilities, that is, in comparison with the other states.

DISCUSSION

F. F. Fowle: This interesting and timely paper by Mr. Norton arrives at a conclusion which seems well worth our serious consideration, particularly from the standpoint of efficient and economical handling of rate cases in proceedings before public utility commissions. The author contends that there is a frequent if not general tendency to over-emphasize certain elements in rate cases—particularly the matter of valuation—and under-emphasize other elements which are possibly quite as important in their effect upon the final result sought. The principal factors in a rate case are particularized by the author as follows: valuation, rate of return, operating expenses, deferred expenses and operating revenue.

If we should attempt to assign relative weights to each of these five elements, in proportion to their respective importance or influence in determining fair and reasonable rates for service, it might

be possible theoretically to do so, but in a practical sense it would be very difficult if not impossible except in rather general terms. I am inclined, hewever, to agree with the author that too much importance, relatively, is often attached to the matter of valuation and undue time and expense devoted to it. From the standpoint of economy and efficiency in handling rate cases it is desirable to survey the problem along rather broad lines, as the author suggests, in order to predetermine so far as practicable how much importance to attach to each of these fundamental factors in the problem and avoid undue emphasis of any one of them.

Valuation of property in rate cases is undoubtedly a fundamental necessity under the laws of most states, if not all, but clearly enough its importance can be overestimated in comparison with the other factors which properly ought to receive due consideration. The point of this seems to me to be that a valuation which is made with reasonable care and sufficient detail for the purposes of rate regulation is clearly good enough, but there are limits as to details of inventory, time required and expense involved, which, if exceeded, cause a valuation to become burdensome beyond all proportion to the additional benefits.

Rate of return has been discussed to such an extent that it seems largely repetition to go into it. It may be worth while, however, to repeat that a fair rate of return to a public utility is or ought to be something more than a return which falls just short of legal confiscation. Authorities generally recognize that the fair rate is comprised of two elements, the first being the customary rent paid for the use of capital under the prevailing conditions, or in other words, the mere interest paid for the invested capital regarded simply as money; the second element is the increment of profit or compensation to the owners for assuming the inherent risks of the business. Naturally the sum of these two elements, or the total fair return, will vary with locality, time and the particular conditions surrounding the business.

Operating expenses considered from the standpoint of a rate case involve an inquiry into the efficiency of operation and management, with comparisons between the utility in question and others of comparable character. The breadth and scope of this field of investigation are so great that questions of the most intricate and difficult character are certain to arise, as experience has shown in specific instances. Detailed discussion of this phase of the subject would perhaps lead us astray from the main thought in the author's paper, but in passing we may observe that the test of reasonableness in judging a standard of operating efficiency or management applies as much here as it does to any other element in the problem as a whole.

Deferred operating expenses relate principally to the matter of provision for accrued depreciation, which is now so well recognized as one of the important factors in rate-making that it demands no special treatment in a discussion concerning the proper balance

among the principal elements in a rate case. Many of the controversies which arise concerning it are the result of opinion testimony, necessarily resorted to in the absence of definite or concrete experience extending through one or more complete life cycles of the plant.

In attempting to estimate the revenue which will be produced by a hypothetical rate schedule, differing in some particulars at least from the prevailing schedule, we encounter another distinctive problem in rate regulation. The commercial effect of a change in rates, as influencing the public demand and in turn the consumption, cannot be predetermined by any exact or precise method of established reliability and even the results of experience in other but similar situations may be far from convincing as to what will actually occur if the hypothetical schedule becomes a reality. The economic laws of supply and demand play their part in some degree, but not to the extent in the case of a regulated local monopoly that they would under conditions of free competition.

In conclusion, I feel we are much indebted to the author for a paper visualizing the subject of rate regulation from such a broad standpoint and tending to open our minds to the importance of establishing a proper balance among the principal factors which come up for consideration in fixing fair rates for public utilities.

Peter Junkersfeld, M. W. S. E.: I was very much interested in Mr. Norton's able discussion on this subject. Regulation began very largely as a matter of perhaps limiting earnings. We deal with two large classes of the public—the consuming public and the investing public. Satisfactory earnings is a thing that we must have to interest the investing public. Rates and quality of service is what interests the consumers. What is the final thing that we are striving for? To give adequate service for reasonable rates. In order to do that we must have additional capital. We cannot get that unless we offer adequate returns.

Some of you have had experience in having bond salesmen call on you. Have you stopped to think how they discuss the subject. It is worth your time to recall how they put it up to you and what kind of a story they have for you. These bond salesmen also are very necessary people in this whole scheme of things. We must always consider what the prime thing is we are after, namely sufficient good earnings to attract capital necessary to render adequate service at reasonable rates in a growing business. In order to get the best results it is only natural that the final authority for regulation should be somewhat removed, as Mr. Norton very aptly put it, from too much local influence. That is the fundamental reason for state rather than local regulation,—far enough away from local regulation, so that an unbiased and fair opinion can be rendered—a fair decision—on all questions that arise between these two parties, the investing and consuming public. In Chicago, fortunately, 85 per cent of the investing public are residents in the same city with

the electricity using public, so that to a considerable extent the two parties have a mutual interest.

Harold Almert: Assuming that Mr. Norton is over in a town, serving a population similar in all characteristics to mine in another town, and I have, instead of $100,000.00 invested (because I am a poorer manager, and engineer), $200,000.00 invested in my property (and that isn't at all unusual to find such a difference in similarly located towns), and I have earnings of about one-fifth of that amount or gross of $40,000.00, and I have a poor operating ratio on about 70 per cent, and so I have net of only $12,000.00. On the basis of the generally accepted fair return, I would be entitled to $16,000.00. Now, I am doing the best I know how, but I am not as good a man as Mr. Norton is. My rates are higher, and say I have 12 cents maximum, and Mr. Norton only a 9 per cent maximum, and he is getting his results, and on the result of some investigation, in view of the 8 per cent returns being allowed, they come in and find that they have to raise this $4,000.00.

Now, that is one of the inherent difficulties that the commission regulation has, as we find it today in a good many states, because of the limitations of the knowledge of the commissions themselves.

Second, because of the limitations put upon them by the law under which they act, and even though they might wish to do better, they find their hands tied until such time as they can get proper amendments to the law and permit them to do otherwise.

Again we muddle up the situation by having very widely differing opinions as to what is to be included in the amount on which to base rates. Of course, that is not part of this discussion tonight, but we may have 150 per cent between us on the two cities or on the sides of this case, on this item.

Just this month, in Ohio, I have been on the case where a man on the other side of the fence has recited something about 45 per cent as much as I have, but I am glad to say that I am told by some of those in authority that I was very conservative and if so, he must have been ultra-conservative. Whether that is the proper place to include something in order to maintain this rate of return within the figure of what is generally understandable, with even an inclination on the part of the commissioners for, perhaps reasons of policy,—believing that they have got to allow more than this figure to maintain this service,—to adjust or allow the increase. However, I have not found anyone over-intelligent in that regard to this time.

I read, with interest, in one of the law magazines, a couple of months ago, an article by a writer from the University of Michigan. In discussing these things, that procedure in regard to valuation is so generally understood and accepted now, that you don't have to go into that, and he dismisses that and goes on with his argument. The principles are generally understood and accepted, he stated.

That was news to me because I had been laboring under the impression that we had not yet established the first principle, and

until we do so, we won't make any real constructive progress, and I think I stated here the other night that my belief is that sooner or later someone will have nerve enough to suggest a principle, and if he gets it right, we will get that as a starting point.

The point that I have had in mind in that regard for a number of years has been that in reasonably well conceived and operated public utilities, the least the investors are entitled to have is to have their principal conserved at all times, and a fair return during the entire time that their money is devoted to the public use. That may not do full justice to some cases, and a good deal more than justice in some other cases, though, if we limit it to reasonably well conceived utilities, it will not give more than they are entitled to, but the return allowed by utilities, when we go into these various phases by allowing for efficiency, would begin to climb and climb fast.

The second item which Mr. Norton has noted,—the rate of return, is the place where compensation for efficiency may be allowed,—if a utility is indeed efficient, they may allow a greater rate of return and no doubt should, but there is where many of the commissions hesitate, because of their idea being on record in some case and if they have allowed a greater rate of return in one case, the fellow who got the lesser return may come back at them and ask for more. So they have many things to contend with.

It is clear, however, that no utilities of this character would have started in the earlier days had they known or believed that they would have been held down to six or seven or eight per cent return. The hazards assumed were too great.

Whether or not a clear distinction can be made and allow a greater return on the earlier investment, and a more limited amount on the more recent investment, is a proposition that will have to be worked out.

Current operating expenses, the third item mentioned by Mr. Norton, is intensely interesting because of the conditions that obtain at this time. In that regard, my worthy opponent, as they call it in Canada, in the case I am now on in Ohio, conceived the happy idea of leaving out in his valuation,—this being a similar property,—leaving out the installation of a 2,000 k. w. turbine. Up to the time of the date of the hearing, some $50,000 had been spent in connection with the installation of the same, all of which he left out. His explanation was that there was installed, up to that time, in smaller units, only 1800 k. w., and obviously the reason for the installation of this 2,000 k. w unit is in order to better the operation. In other words, the greater efficiency of this 2,000 k. w. turbine, in his judgment, would be such that the company would not only have lower operating expense, but, all things considered, would earn a very handsome return by its installation, so that it wasn't necessary to consider it in the capital account.

The facts of the case were, if he had taken the time to inquire, normal extensions to the business, had required the installation of that particular feature, and the business was in excess of its capacity

before the installation was completed, and he did not know that this same company already had an order in for a 5,000 k. w. unit, but according to his argument, it would be right and proper, as soon as that new unit was installed, to write them into capital account, and write out all the rest of it, because of the greater efficiency of the new unit, and he figured that the earnings would be such that the company would have, in addition to the present earnings, a very largely increased earning from the operation of the new unit, and he would attempt to come in by the next time we got together, and figure out what those savings would be, and, after the adjournment, I asked if we could not simplify matters (because I expected that he would have a table I would have to refute), I asked if we could not shorten matters by admitting that hereafter they would have to consider no addition to capital stock, because whatever the requirements were the savings would be so great that the "Lord would always provide."

Under those circumstances, with such unfair engineers on one side or the other, it is difficult for the commission, which is not composed of engineers, to ferret out, by looking the engineers in the eyes and trying to tell which is the fair one, and which knows whereof he speaks, and which does not.

So, the commission is still having its troubles, and while I am with Norton in the belief that regulation is the proper thing, and that it will ultimately succeed, revenue, or fair revenue cannot be determined, until all these other elements are worked out.

Just to complicate matters a little bit more, I want to mention one more item which is generally overlooked. I have come in contact with it so forcibly, so many times recently—we hear frequently in rate cases the element of franchise should not be considered. The reason given and that is borne out by a great many decisions, is that it is a grant to the corporation by the public. Nothing is paid for it and for that reason it should not be capitalized, as against the public in arriving at an amount on which to base future rates.

I have found in the east that there is another value which has been brought out by the courts. Namely, the value of property rights in easements, and the courts make a clear distinction between the mere right or grant of a right to engage in the public utility business, and the rightful occupation of public space, the streets as well as easements over private property by virtue of the ownership of that franchise, the courts say, is property, and have clearly so decided in a number of cases. If it is property, it is up to the engineer to include it in the amount which he determines in the reproduction cost, or on whatever basis he is working.

The principal reason I ask why it has been left out is because of the difficulty of determining its worth, but there again the courts tell us that because it is difficult to ascertain, there is no reason for leaving it out, if indeed it has a value. As an illustration, in the consolidated gas case in Baltimore, in 1912 and 1913, the Public

Service Commission found that the principal elements which were included in the valuation amounted to some eighteen million dollars, and the company made claim for seven million dollars additional as the value of property rights in easements. They referred it to the attorney general of the state for a report, and he reported that it was a property element of the value and must be included in the rate case. The difficulty then was, "Well, what is it worth?" The tax commissioner in the city of Baltimore had assessed the company five million dollars for those rights, and for want of a better basis, the commission accepted that and added to their physical valuation of eighteen million dollars, five million dollars for the property rights and easements.

In Maryland those rights have been given a definite status. In the District of Columbia, the case has come up a number of times. As an illustration, Congress ordered the Citizens Street Railway there a few years ago to extend one of its lines a half mile. Co-incident with that order, it ordered the widening of the street one hundred feet from curb to curb, and assessed the street railway company twenty-five thousand dollars as their share of the improvements. The company contested it and said they had no property and therefore could not be assessed, but the Supreme Court stated that in giving the company the right to lay its tracks, Congress had conferred upon the company property rights, which were their property, and they could not be deprived of those rights without compensation, and neither could the public use them without compensation, and therefore they could also be assessed for improvements the same as abutting property owners.

All these cases, by the way, are cases where these property rights are perpetual, and not with a limited franchise, but what effect that would have I am not prepared to say.

Just as an illustration, in the Baltimore case, the telephone company has not the same rights, and they have to pay the city of Baltimore twenty cents per lineal yard for the right to lay their conduits, and seven cents a foot for the use of the street for their pole lines. The rental which they pay, capitalized between six and seven per cent, assuming they have the same rights, gives them the same figures, or five million dollars for their rights.

I could go on at length and cite a number of cases, but I am not going to trouble you with them tonight, except simply to cite some of the difficulties we are going to have in the evolution of this matter of regulation in determining the worth of these things. I was glad to be permitted in the course of my testimony recently to put in as much argument as testimony on this particular subject, because it was new to them, and the commissioners listened with a great deal of interest, and there I did the only thing which we are told not to do, namely, consider the earnings in determining valuations, the generally accepted idea being that earnings depend on rates, and that we cannot consider earnings as we are reasoning

in a circle, but if we determined all the other elements before we consider this one, all the other elements being that of cost, this one being one of value, because nothing was paid for them, we can consider earnings, and its effect thereon, without muddling up the situation. There again, I think is one of the principal difficulties we encounter now; that in certain states the cost of production is assumed to be the only basis, and there it is assumed that reproduction cost is value. In other words, that the cost cannot create a value which is greater, although the costs are not equal.

Going back to the subject of the paper, more particularly, we should be congratulated on having Mr. Norton direct our attention to these particular items, because I know of one case now where the costs of valuation have exceeded one hundred and fifty thousand dollars. A settlement has not been reached and I don't know yet what the value is, but even now the company involved has not begun to find out about these various elements about which Mr. Norton has told us tonight, and which are essential, and they have just reached that same point, as Mr. Norton said, where everybody is tired of the case now,—sick and tired, and looking for an adjustment and settlement of some kind, and I am sure that these elements should be determined, first, on the rate of return as to the whole affair and as between the class of customers, is the return fair as based on the amount of the property devoted to the particular use.

I had never heard the term until Mr. Norton used it tonight as "deferred operating expenses," as another name for depreciation. There again we have a wide opening for a great deal of consideration. The simplest form in which I can bring it to my own mind for consideration is that if, from a careful consideration of the company and the investment, from its inception, it is demonstrated that the company has not had to exceed a fair return—I better put it this way—if the earnings in the past have been such that the company has had only its operating expenses, taxes, and a fair return, then the actual depreciation is an obligation which the public must assume to make good and should be added to the account, or to the sum on which rates for the future are to be based.

Second, if the earnings have been equivalent to all operating expenses, taxes and depreciation, and the property has been maintaind in one hundred per cent service condition, there should be no deduction from the reproduction, or whatever basis is used.

Third, if the operation has been such that the company has had its operating expenses, taxes, fair return and an amount to make good the depreciation, and it has failed so to do, so that the property is in a condition that it will not render one hundred per cent service, then there properly is to be a deduction in such an amount as will be necessary to make good the parts affected, and to put them in one hundred per cent operating condition.

C. F. Elmes: I am in accord with almost all the remarks we have heard this evening, and in particular, I have been greatly impressed with Mr. Norton's paper. It is an unusually clear and lucid exposition of rate regulation as generally practiced today.

Our firm, Sanderson & Porter, is now working on a case which we are trying to negotiate with the city of Chicago, and there are two or three points in what Mr. Norton and some of the other gentlemen have said that have very greatly interested me.

One of these points I am not going to elaborate on at all, I will barely mention it, and that is the rather pointedly expressed opinion here, that it is better to have a commission to deal with than a city government. In this particular case, to which I refer, we happen to be trying to deal with a city council in getting suitable rates, and while, of course, we may not succeed, we certainly hope to do so. We hope to get fair rates for the company, ones they can live under and develop their business.

Taking the gas industry as a whole, Mr. Norton touched on a point which makes that utility very different from anything you have in the electrical industry, makes the gas business a very dry and lean business. That is the almost universal flat rate which the gas people have in effect all over the country. We have looked into the matter a good deal, and we have been surprised to find the remarkable effect it produces on the companies' business.

An electrical company, as a result of maximum demand rates and the various other differential rates which are offered to get the business of the large consumers can hope to sell as much as 80 per cent of their energy to big consumers with, perhaps, only 20 per cent going to small or domestic consumers. That is, they sell 80 per cent of all of their kilowatt hours to the man who really adds to their business and makes it grow. The gas companies cannot do that with their flat rates. They have an enormous number of consumers, of which the great majority are very small users, some of them ridiculously small. In the case of a gas company, the ratio I mentioned for the electric business may be almost reversed. In other words, the gas company may sell 80 per cent of its gas to the small or domestic consumer whose rate of use grows slowly, if at all, and only 20 per cent to the big consumer to whom they should look for large scale development. Now, that is a very unhealthy condition of affairs. It is something that the gas industry should remedy, and that we hope to see remedied by the devising of scientific rates to replace the old flat rates.

Mr. Norton spoke of the significant fact that in rate making a valuation of the company's property is taken as the basis in establishing the rate. That is generally true and at times it seems as if it hardly ever occurs to any one, that there are other bases which might be used with better all-round results.

Now, we believe there are other bases and methods that can well be used in determining rates. More than that, we believe that there is a broad business viewpoint or principle which may often render a valuation, with all its inventory and appraisal work, superfluous and wipe it aside. That principle is the mutual interest of the consumer and the investor in the successful operation of a public utility.

Consider the position in which the manager of a public utility

property is placed. He has two sets of critics to satisfy, his stockholders and his consumers. On the present prevalent basis of regulation he cannot possibly please both parties. If, at his stockholders' meeting, he announces, "Gentlemen, we are ready to declare large dividends as a result of the year's work," his consumers instantly become resentful and clamor for a reduction in rates. If he says to his consumers, "Gentlemen, we are going to give you the lowest rates in the country," his stockholders will probably object. They may ask for more dividends or become nervous as to the continuance of their dividend payments.

Surely this is an unhealthy and wrong condition for the industry to be in. The most discouraging feature of Mr. Norton's able paper, and of Mr. Almert's comments upon it, is the clear inference that present rate fixing procedure holds out no encouragement to able and aggressive management. If we are to have progress, it is imperative that a normal and healthy human incentive to good management be put back into the public utility business. What is needed is a scheme whereby if a company reduces rates it is automatically allowed to pay larger dividends. Some remedy must be found along these lines.

There is one that Mr Norton touched on this evening, although he had not a very good word for it, that is, the plan of a sliding scale of dividends and rates combined, in other words, a fair profit-sharing scheme. Mr. Norton mentioned that it had been attempted in Boston and was not a success. That is true, they tried it there and it failed. Why it failed is a matter we need not go into here, but it is a misfortune to the whole public utility business that the Boston experiment did fail.

There is no basic reason, however, why it should fail elsewhere. The thing has been done in England; it was evolved there years and years ago and works well. There they fix a minimum dividend which the company is expected and allowed to earn before the consumers have a claim to a share in the surplus. Generally speaking, this minimum dividend in England is 10 per cent,—they do not think over there in terms of 6 per cent. Possibly such a minimum dividend would be too high for general use in this country. I do not know whether public sentiment would support a minimum dividend as high as that.

We are not greatly interested in the mechanical details of the profit-sharing scheme to be adopted. There are many different ways in which the thing can be done. Nor are we particularly insistent as to the point or method of fixing the minimum. Fix it at some fair per cent, whatever such may be, but after the percentage is fixed, then let us have a scheme whereby if a company gives low rates, it may pay high dividends. If the public, instead of getting electric light at present prices, could get it for considerably less, while the electric light company raised its dividends to 12 per cent or 15 per cent, we believe that all would be thoroughly satisfied. Give the public and the consumers both a personal interest in having

the public utility pay large dividends, because with large dividends on this basis there will go low rates for electric light or gas. That is what we wish to achieve by means of proper profit-sharing.

A. C. King: I think that all of us that have had any experience at all in the regulation proposition agree with Mr. Norton on many of his ideas. Coming to the subject of commission regulation, I think we also appreciate the shortcomings of the commissions, but I think, if we analyze the problem a little bit from their standpoint, we will see why they apparently have felt themselves limited in their decisions and the reasons why their work has generally followed a beaten path.

One of the most important reasons, or rather, the most noticeable reason, as I see it, is that if the commission makes a finding in a certain case, either one party or the other is dissatified and it is then an appeal is taken to the courts in a great many cases. Now, we all know that the courts follow along beaten paths; they don't branch out into new fields; practically never do. Our laws are all based on the old English laws of centuries standing, and in fact, the greater percentage of the court decisions are based on no laws at all, except precedent. For that reason the commissions must, to a certain extent, anticipate court findings, they feel that they must be guided largely by precedent.

This fact rather limits the entire subject, and as I believe, has a tendency to make the matter of regulation largely a routine proposition, and the commissions, I believe, have come to so regard it.

I know, in a case in which I was recently interested, before the testimony was taken the sitting commissioner made a little preliminary statement in which he went on to relate the various factors involved in rate making that have been mentioned by Mr. Norton.

"Now," he said, "we expect that testimony will be presented along all these lines and when both sides have presented their testimony on these subjects, it will be a very simple matter to determine what the rate should be." "It isn't even necessary that the commission shall decide it," he said, "anyone of you men here can decide it after the testimony is all in. You can tell in advance what our ruling will be on this subject in this case." I think any of you gentlemen who have had experience with commissions would almost be willing to take a chance on flipping a coin rather than to try to reason out the finding of the commission from the testimony.

But that statement, it seemed to me, indicated the commission's tendency to handle these matters in a cut and dried sort of way, and as they look on it as a routine matter they have no particular tendency to reach out and develop and expand the scope of their work along original lines. And in this case, one of the other commissioners made the statement that rate regulations, he thought, had been complicated within the last year or two by the prominent part which lawyers were taking in it. He said that as long as engineers and accountants handled it, they found the course very much simpler and the work was therefore greatly facilitated.

PROCEEDINGS OF THE SOCIETIES

Minutes of the Meetings

Meeting No. 969, April 30, 1917.

The meeting was called to order about 8:00 p. m. by Chairman Stineman, of the Bridge and Structural Section, with about 100 members and guests present. The Chairman introduced the speaker of the evening, Mr. S. Moreell, Jr., who read an abstract of his paper, "The Method of Ellipse of Elasticity and Its Application to Continuous Arches on Elastic Piers," which had been sent out in advance to all of the membership. The paper was illustrated by lantern slides. Written discussions, prepared in advance of the meeting, were read by Prof. S. C. Hollister, of the University of Illinois, and by Mr. M. D. Kolyn.

The meeting adjourned about 10:30 p. m.

Meeting No. 970, May 14, 1917.

The meeting was called to order about 8:00 p. m., by Chairman Stineman, of the Bridge and Structural Section, with about 60 members and guests present.

The Chairman announced that the following had been elected to the grades indicated:

No. 24, George Scheppach, Chicago................Student Member
No. 26, Henry L. Potter, Chicago................Associate Member
No. 27, James E. Noonan, Chicago..............Associate Member
No. 28, Tenney S. Ford, Chicago...............................Member
No. 29, A. Leslie Cummings, Chicago..............Student Member

and that the following had made application for membership in the Society:

No. 30, Herman N. Simpson, Chicago, transfer from Student.
No. 31, William G. Born, Chicago.
No. 32, Chason W. Brooks, Chicago, transfer from Associate.
No. 33, Roland S. Fend, Chicago.
No. 34, Clifford H. Landis, Chicago.
No. 35, Hubert V. Stephenson, Chicago.
No. 36, Charles A. Miller, Jr., Chicago.
No. 37, John D. Barber, Chicago.

The Chairman then introduced the speaker of the evening, Mr. T. D. Mylrea, Assoc. W.S.E., who presented his paper on "The Behavior of the Flat Slab Concrete Building in the Quaker Oats Fire at Peterboro, Ontario." The paper was illustrated by lantern slides. Discussion followed from Messrs. N. M. Stineman, S. H. Ingberg, W. C. Robinson, F. W. Fredericks, W. M. Kinney, James N. Hatch, O. F. Dalstrom, J. W. Lowell, Jr., James S. Stephens and A. C. Irwin. Mr. Mylrea then showed some samples of brick, concrete and glass which had been in the fire.

The meeting adjourned about 10:00 p. m.

Meeting No. 971, May 21, 1917.

The meeting was called to order about 8:00 p. m., by Chairman Maury of the Hydraulic, Sanitary and Municipal Section, with about 60 members and guests present. The speaker of the evening, Mr. H. W. Clausen, Assoc. W. S. E., was then introduced, who presented his paper on "Surveying Methods on the Wilson Avenue Water Tunnel," which was illustrated by lantern slides.

Mr. E. T. Perkins, M.W.S.E., spoke about the Red Cross and with a few assistants solicited subscriptions to it.

The meeting adjourned at about 9:15 p. m.

Meeting No. 972, May 28, 1917.

This was a joint meeting of the Chicago Section, American Institute of Electrical Engineers, and the Electrical Section, Western Society of Engineers, and was called to order at 7:50 p. m., by Mr. Taliaferro Milton, Chairman of the Chicago Section, A.I.E.E., with about 150 members and guests present.

Motion pictures, donated by the Westinghouse Electric Co., were shown and proved to be very interesting.

Chairman Milton then turned the meeting over to Mr. F. F. Fowle, who introduced the speaker of the evening, Prof. William S. Franklin, who presented his paper on "Electric Waves," which was illustrated by lantern slides. Discussion followed from Prof. Bauer of Northwestern University.

The meeting adjourned at about 11:00 p. m.

B. E. Grant, *Acting Secretary.*

Journal of the

Western Society of Engineers

Vol. XXII JUNE, 1917 No. 6

INTERCEPTING SEWER CONSTRUCTION IN THE NORTHERN PART OF THE SANITARY DISTRICT OF CHICAGO

By H. R. Abbott, M. W. S. E.*

Presented June 4, 1917.

In this paper are described methods of work, construction problems and difficulties and methods of solution on some eighteen miles of intercepting sewer construction in the northern end of the Sanitary District of Chicago. Cost data on a large portion of this work is also presented.

As some of you know, the primary purpose of the Sanitary District is the disposal of the sewage of the City of Chicago and some 32 surrounding municipalities, by diversion of the Chicago River into the main channel. Further, the discharge of the river into Lake Michigan prevented, thereby removes a pollution which for years contaminated the water supply and endangered the lives and health of not only the resident but also the transient population of the city.

Following the annexation in 1903 of the territory lying between the northern limits of the city and the north line of Cook County, the North Shore Channel was constructed, from Lake Michigan at Wilmette to a connection with the North Branch of the Chicago River at Foster Ave. This channel, completed in 1910, is 8⅛ miles in length, built with a base of 26 to 30 feet with side slopes of 1 vertical on 2 horizontal and 3 vertical on 5 horizontal. Subsequent slides on a portion of these slopes necessitated a resloping which has recently been completed. This resloping was done by the hydraulic method, making the slopes 1 vertical on 3 horizontal above the water line. The capacity of this channel is 1,000 cu. ft. per second with a 3 ft. head at the Wilmette Pumping Station. This station is equipped with 4 horizontal screw pumps, each 9 ft. in diameter with a capacity of 250 cu. ft. per sec. each, at 75 r. p. m. The pumps are geared to 150 H. P. alternating current motors, 3 phase, 60 cycle, 440 volts, operated by Sanitary District power gen-

*Assistant Engineeer, Sanitary District of Chicago.

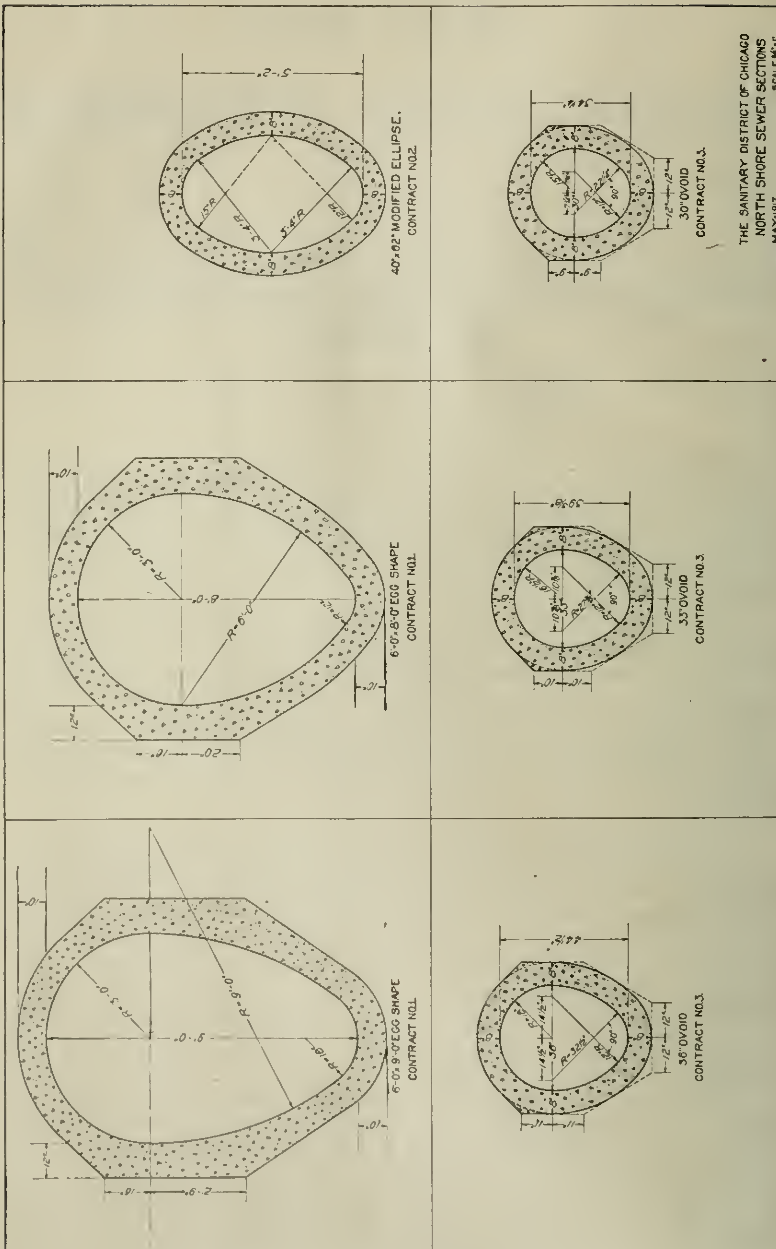

Fig. 2. North Shore Sewer. Sewer Sections.

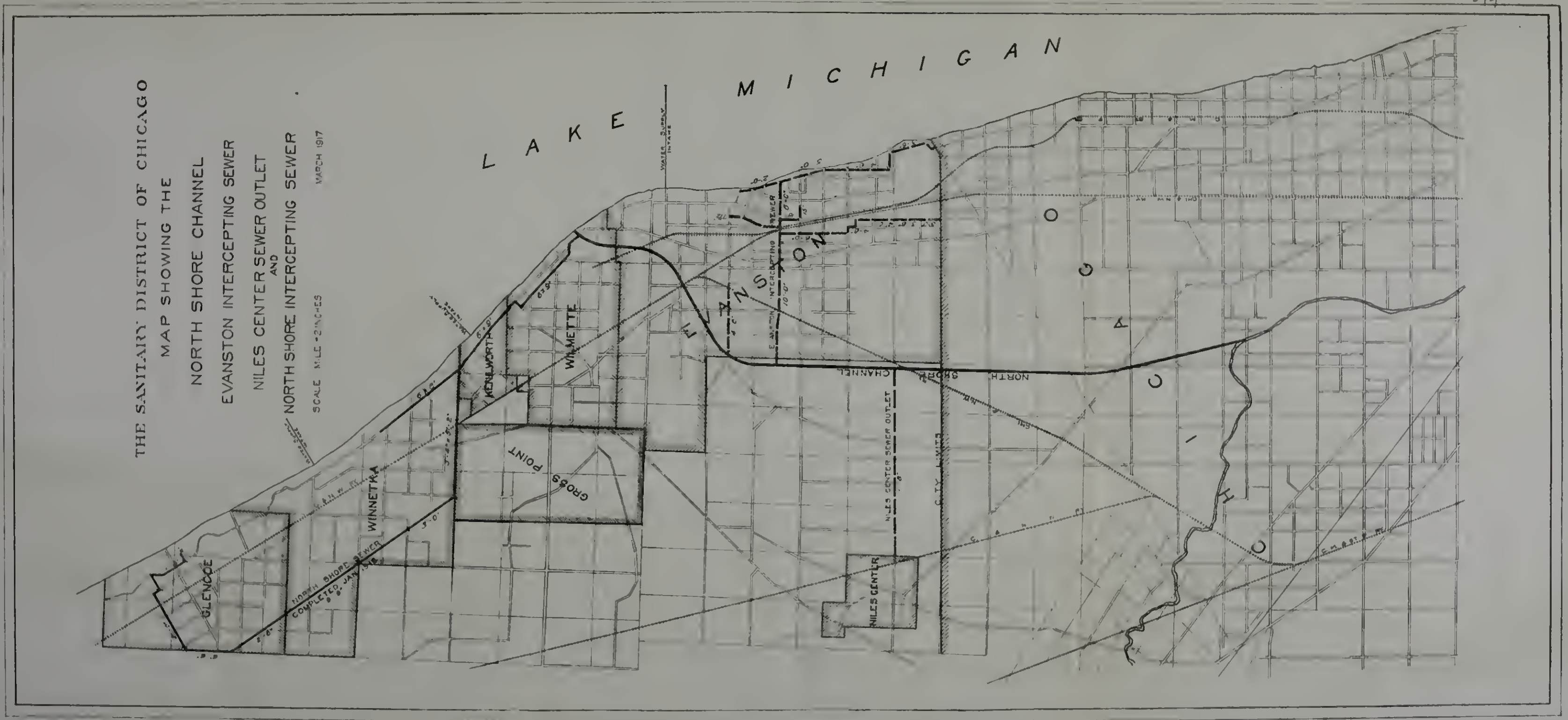

Fig. 1. North Shore Sewer. North Shore Towns, Map Showing Route of Sewers.

erated at Lockport. The gradient of the canal is 1 in 20,000 and depth of water is 13.6 ft. This entire work including the pumping station, right of way and bridges was completed at a cost of approximately three and one-quarter million dollars. This channel affords the outlet for the intercepting sewers; one, the North Shore Intercepting Sewer, completed Jan. 1st, 1916, the other the Evanston Sewer, now under construction. (See Fig. 1.) The North Shore intercepting sewer, about 9 miles long, serves the villages of Wil-

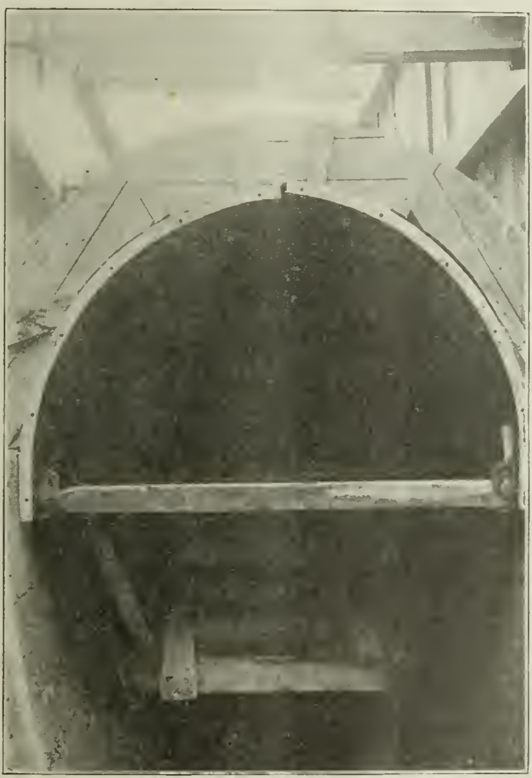

Fig. 4. North Shore Sewer. Blaw Steel Forms for Arch, 6 ft. by 9 ft. Sewer—Open Cut—Contract No. 1.

mette, Kenilworth, Winnetka and Glencoe, intercepting five sewer outlets from Lake Michigan and four from the Skokie. Preliminary work started in the summer of 1913. Transit surveys covering the proposed route were made and profile levels run, making return circuits, establishing bench marks and tying up the local bench marks of the four villages. The datum plane established in some of the villages was found to be different from the Chicago city datum. Test

borings were also made over the route, the borings being spaced about ¼ of a mile apart. The entire project was divided into three contracts. Contract No. 1, 2.7 miles in length, began at the North Shore Channel and extended north in Sheridan Road through Wilmette and Kenilworth, terminating at Cherry St., Winnetka. Contract No. 2 was 1.3 miles long, branching from Contract No. 1 at Winnetka Ave., Winnetka, and extending west largely in tunnel,

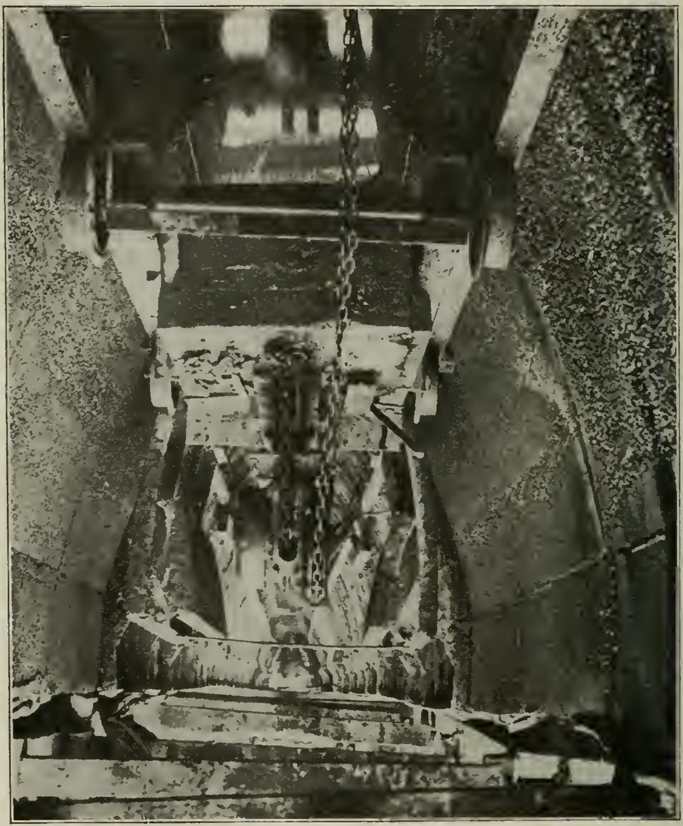

Fig. 5. North Shore Sewer. Traveler With Boom for Carrying Invert Forms of Blaw Type Ahead in 5 ft. Sections—Contract No. 1.

to a junction with Contract No. 3. Alternative bids were taken on these two contracts on concrete, brick and segmental concrete blocks, reinforced, the brick running 10% and the segmental blocks 20% above the monolithic concrete. Contract No. 3 was 4.7 miles in length, extending in a northwesterly direction along the western limits of Winnetka and Glencoe, skirting the eastern edge of the Skokie Marsh, and turning eastward in Milton Ave., Glencoe, pass-

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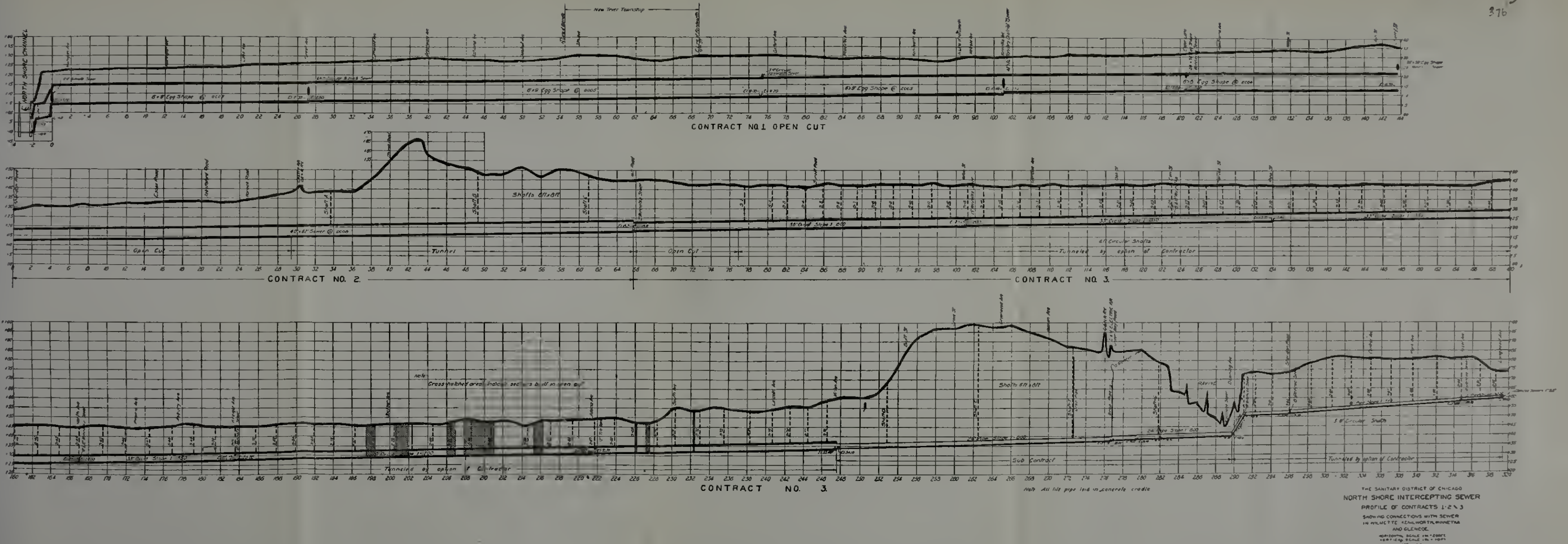

Fig. 3. North Shore Sewer. Profile.

ing under C. & N. W. Ry., traversing a large ravine and terminating at Longwood and Hazel Aves., Glencoe. The first dirt was turned by Governor Dunne, following appropriate ceremonies at the New Trier High School, Winnetka, on April 4th, 1914. Actual construction started on Contract No. 1 at the North Shore Channel on May 5th.

Contract No. 1 (see Fig. 3) was built entirely in open cut, av-

Fig. 6. North Shore Sewer. Concrete Mixer Astride Trench, 6 ft. by 9 ft. Sewer, Sheridan Road—Contract No. 1.

eraging 21½ ft. The excavation was made by a Bucyrus 70-ton steam shovel, mounted on timbers to span the trench, and fitted with a 54-ft. dipper handle. In the maximum cut of 26 ft., some hand work was required on account of the excessive depth. The average daily progress for an entire working season was 70 ft. or 480 cu. yds. of excavation. The maximum daily run was 125 ft.

or 850 cu. yds. of excavation. All sheeting was left in place to prevent any sloughing of the banks, largely, however, to protect the local sewer and water pipes close by, although the entire section was in good stiff blue clay. For sewers from 4 to 15 feet in size in open surroundings the steam shovel affords a most economical and efficient machine for excavation. The sewer section of this contract is egg-shaped, built of monolithic concrete of 1:2½:5 mix and is 6x9 ft. in size, merging into a 6x8; the slopes are 1 in 2,000 and 1 in 2,500, respectively. The discharge into the canal is through

Fig. 7. North Shore Sewer. Blaw Steel Forms for 40 in. by 62 in. Sewer in Tunnel—Contract No. 2.

a submerged outfall. Blaw steel forms were used, of a collapsible type, the sections being 5 feet in length. Both invert and arch forms were carried ahead by travelers. The arch traveler was 12 feet long, carrying 15 feet of form per trip. This traveler was carried on 9 in. flanged wheels, running on a small T rail, supported on cross timbers placed about 3 ft. above the invert. The invert traveler carried one 5 ft. length of form ahead each trip, suspended from a small boom equipped with wire rope, clevises and winch; the rear end of this traveler being counterweighted to

maintain stability. For the job 130 ft. of invert and 200 ft. of arch forms were employed. The invert form was supported on concrete blocks 9x10x14 in., spaced 5 ft. on centers. These blocks were cast outside the trench and cured, being placed to line and grade as soon as the bottom was shaped up, after which the space between the blocks was filled with concrete from the mixer. The concrete mixer was mounted to span the trench, depositing the concrete through a flexible jointed chute. (See Figs. 4, 5 and 6.)

All material was teamed to the work, the average haul being 1¼ miles. Spoil was loaded direct from the shovel into 2½ yard dump cars and hauled to the dump or the backfill, seven cars forming an average train. The dump was situated in a ravine and along the shore of Lake Michigan near the middle of the contract and was secured by the contractor by private arrangement. Dumping was carried out parallel with the bluff, making 30 to 40 feet of additional land, level with the balance of the property, some 1,500 ft. in length, lying 30 ft. above the lake level.

Four sewer outfalls, discharging into Lake Michigan were intercepted on this contract. Three were provided with spillways, utilizing the old sewers between the intercepter and the lake as overflows for excessive storm flow. An output of 0.8 ft. of completed sewer per day per man was obtained. This is good progress for a sewer of this size and depth.

Contract No. 2 comprises a modified ellipse-shaped sewer 40 by 60, two inches in size, built partly in open cut and partly in tunnel with a slope of 1 in 1,250. (See Figs. 2 and 3.) On the open cut section a Parsons excavating machine was used, spoiling alongside the trench. As the work was in an unpaved street, continuous sheeting was not used. Several cave-ins occurred due to leakage from an existing tile sewer parallel to the work, which at places was exposed in the side of the trench. The Blaw forms used on this section were in 5 ft. lengths, five lengths being bolted together as one unit when moving ahead. The concrete invert or dish was laid ahead, the invert forms then being dragged ahead by block and tackle. The arch forms were equipped with 5 in. castor wheels, bolted to the forms, and were carried on wooden stringers supported on cross timbers, the collapsing of the forms being done with a turnbuckle attached to the forms and also serving as a cross-brace. Fifty feet of invert and the same amount of arch forms were used on this section.

Concrete was mixed in a Whirlpool gas engine mixer, capacity ten cu. ft., and chuted into the work. Very little excavated material was hauled away and backfilling was done by teams. Progress on this section was very slow and the cost data given later illustrates the difficulties faced by the contractor on this particular piece of work. The output was only 0.66 ft. per man per day or a daily average progress of 25 ft.

From the east right-of-way line of the C. & N. W. Ry., to

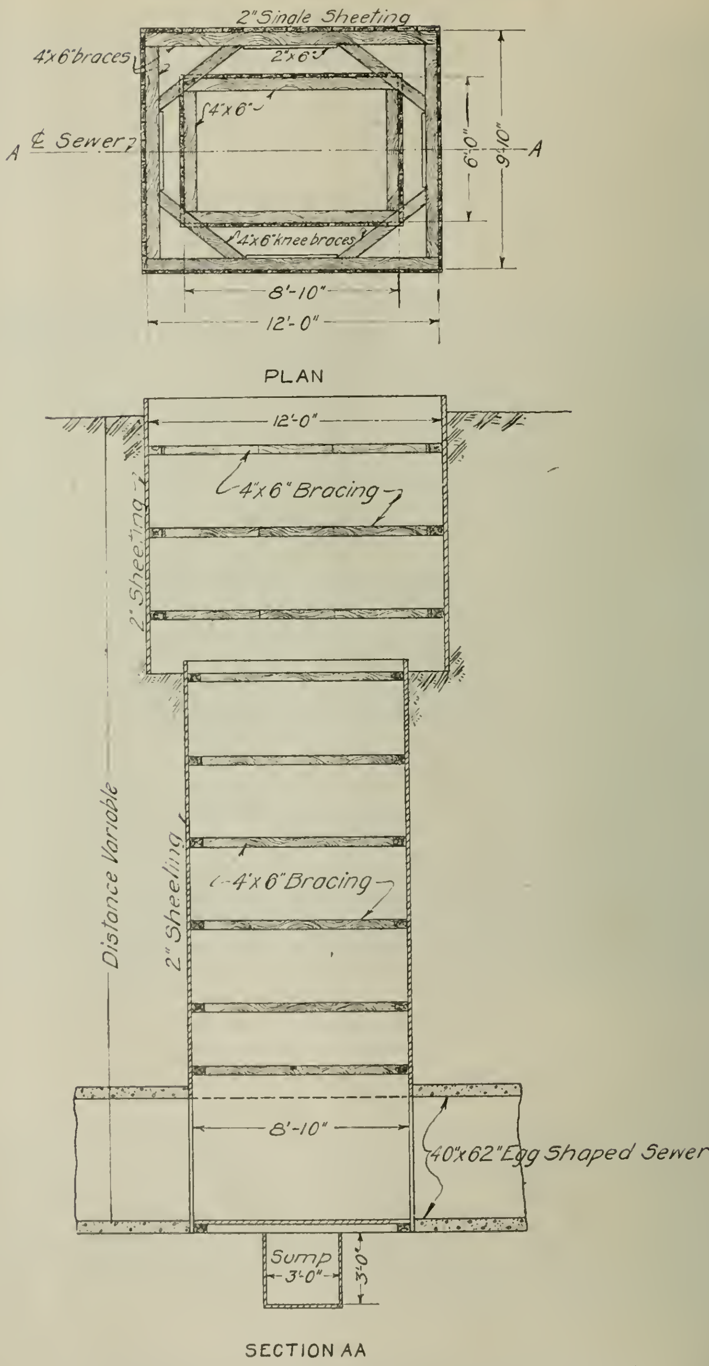

Fig. 8. North Shore Sewer: Timbering Plan for Shafts on 40 in. by 62 in. Concrete and 24 in. Tile Sections—Contracts 2 and 3.

the west end of this contract, the sewer was built in tunnel passing under the Indian Hill Golf Club. Three shafts were sunk, shown on the left hand portion of middle frame of figure 3 as shafts A, B, and C, and averaging 1,400 ft. apart. The length of the headings varied from 600 to 900 ft. The shafts were all rectangular, 6x8 ft. inside (see Fig. 8.) In sinking the shafts the excavated material was scaffolded up. The work in the tunnel was carried on 24 hours a day in three shifts, two mining and one concreting. Owing to the nature of the ground very little timbering was necessary, occasional crutches and light polling boards being used where the roof showed a tendency to slough off and in all such cases the polling boards were concreted in, but the crutches were removed. A regular mining program of ten feet for each eight hour shift in each heading was followed and this twenty feet mined each day was lined in the eight hour concrete shift, making a total progress of forty feet in the two headings every twenty-

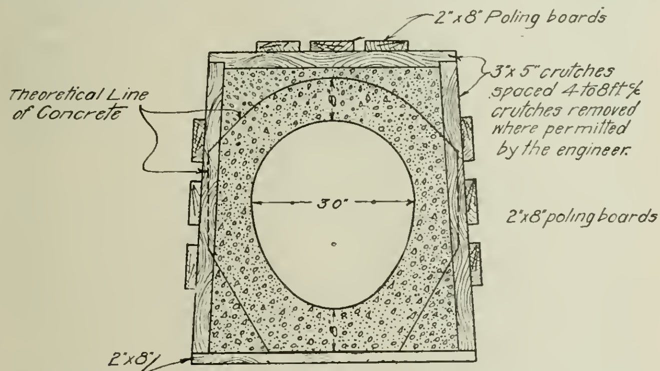

Fig. 9. North Shore Sewer. Timbering Method on 30 in., 33 in. and 36 in. Sewer in Tunnel on Skokie Line—Contract No. 3.

four hours. This is equivalent to 0.75 ft. per man per day and is good progress for tunnel work of this size. Concrete for lining the tunnel was mixed at the top of the shaft by hand, loaded into muck cars and pushed by hand to the headings. A strongly timbered two-story head-house carried the elevator which was operated by a steam hoist. The muck was raised to the second landing and run out onto a dump track to be dumped onto the muck pile or into wagons. At the completion of the tunnel-work driven from any one shaft, the head-house, hoist and boiler were moved on to the next shaft. Ventilation for the tunnel was furnished by blowers operated by a belt from a special engine. The Blaw forms for this tunnel section were the ordinary knock-down forms consisting of ribs and lagging plates, plates 5 feet long by 18 to 21 inches in width; 80 lineal feet were used on this section. (See Fig. 7.)

Contract No. 3 extended along the eastern edge of the Skokie Marsh, on a diagonal line, cutting through the private property,

including subdivisions, farm land, private estate and the Skokie Golf Club grounds. About three and one-half miles of this contract was built on easements obtained from the property owners, then turning eastward through Glencoe to the lake. The contract included 36, 33, 30 inch ovoid shape concrete and 24, 18, 12 and 9 inch tile sewers, beginning with a slope of 1 in 1,500 and gradually increasing to 1 in 540 at upper end. This contract section was specified to be built in open cut, except the 4,200 ft. of 24 in. tile on Milton Ave., Glencoe. The contractor, however, after building the first 1,100 feet north of the junction with contract No. 2, and making very unsatisfactory progress, decided to build all of the balance in tunnel. The open cut work showed that the tunnel would be in fairly good clay, although the first six feet below the ground level was a very sandy loam, and would give trouble in an open cut unless Wakefield sheeting was used. Shafts were sunk at short intervals for the entire balance of the work, or 3¾ miles, this stretch having 92 shafts with 184 headings. The headings aver-

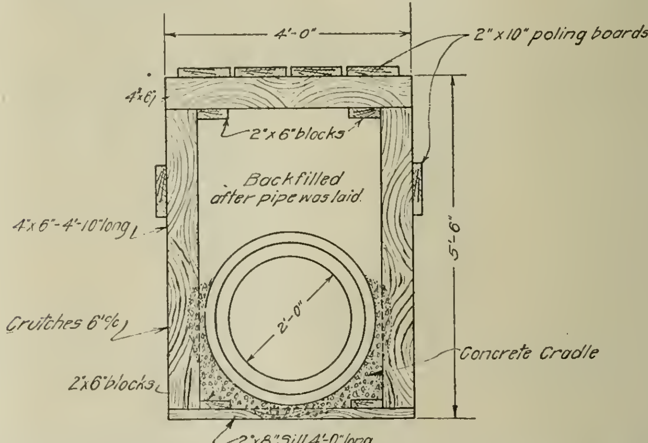

Fig. 10. North Shore Sewer. Timbering Method on 24 in. Tile Sewer in Tunnel, Milton Avenue, Glencoe. Contract No. 3.

aged 207 feet in length on the 36, 33, 30, 18 and 12 in. sections, but not the 24 inch tile section in Milton Ave. The total length of shafts of this character was 1,943 lineal feet or just about ten per cent of the entire length of the tunnel as built from these shafts. An average day's progress on this work was 57 feet, including the shaft work, or very nearly one foot per man per day, as against a progress of but 25 feet per day on the 1,100 feet done by open cut on the same sewer. This change in methods will be further illustrated later in the cost diagrams. Owing to the extremely small working space in these sections, it was impossible to concrete the sewer as the work progressed. The expedient was therefore adopted of mining continuously between shafts and concreting the

whole length of the heading from the face back to the shaft after the mining had been completed. These shafts, averaging only 21 feet in depth, were circular and 6 feet in diameter, using the ordinary sewer iron rings and 2 inch wood lagging. These were sunk by two special crews, the first excavating and sheeting the shaft to a depth of 10 feet and scaffolding out the material. The second gang completed the shaft and usually cut and timbered the eyes, hoisting the material out with a carriage wheel winch, such as is used for lowering pipe into a trench, but geared up to give more speed.

Because of the frequent shifting required, very little plant was used. Two light two-story timbered head-houses, built on skids, were used, one being in operation at the shaft where mining was

Fig. 11. North Shore Sewer. Inside Form for Concrete Manholes Built of Staves and Rings. Contract No. 3.

under way, while the other was set up at the shaft ahead. The power plant was a single drum hoist and a portable 30 h. p. boiler. The whole outfit was moved ahead, set up and put in operation in less than two hours. Muck was brought from the face to the shaft in tubs carried on small flat cars. No elevator was used, the tubs being hooked directly onto the hoisting table, raised to the second landing of the head-house and dumped into the spoil wagons. Concrete was fixed in a Whirlpool gas engine mixer of ten cu. ft. capacity, and chuted down the shaft into dump cars which were pushed to the headings. Forms were removed by a special gang after the concrete and mining gangs had gone on to the next shaft. This gang also pointed up, plastered the invert and concreted up the opening at the shafts. The forms used in concreting

the shaft opening had to be removed through the next shaft. Sand pockets of considerable extent encountered along a stretch of ¾ of a mile prevented the work being done in tunnel at these points with the means at hand. The work at these places was then carried on by the open-cut method, making the excavation by hand, the total open cutting in eight separate pieces totaling 723 feet in the 3¾ miles of work; these open-cut sections proving very expensive to the contractor. Built-up wooden forms were used on the 30 and 33-inch sections (see Fig. 13) and the Blaw steel forms on the 36 inch section, using 128 feet of the steel forms and a similar

Fig. 12. North Shore Sewer. Portable Head-House, 2 Head-Houses Used on 92 Shafts. Contract No. 3.

length of wood form on the other two sections. All material was delivered by teams and for about one-half on the contract section it was necessary to lay plank roadways extending from the end of the nearest paved street to the site of the work. The planking in these roadways, however, was taken up and used again and again. The average haul for material was one and one-half miles. Four outfall sewers were picked up on this contract, intercepting the sewage which formerly flowed away in open ditches.

The 24 inch tile section was specified as tunnel in the contract; it was driven from four shafts averaging 49 feet in depth, spaced approximately 1,000 feet apart, making the headings 500 ft. long. All shafts were sunk at the site of manholes and other manholes

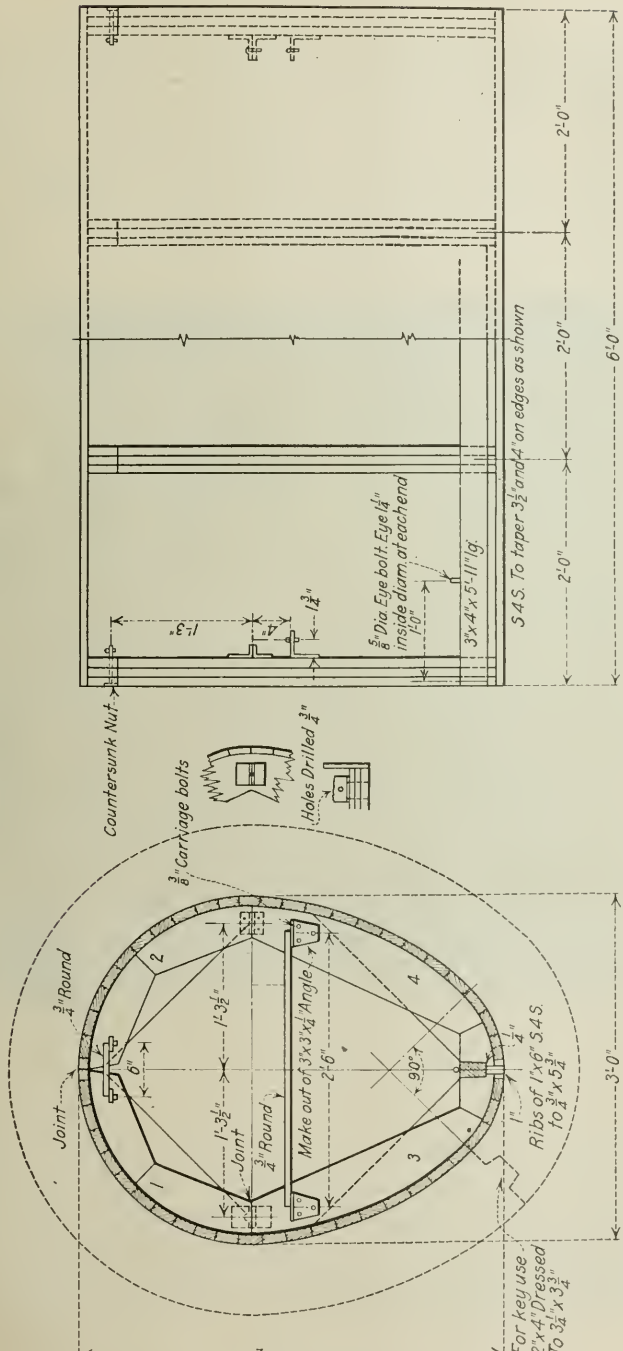

Fig. 13. North Shore Sewer. Built-up Wooden Forms, 36 in. Section in Tunnel. Contract No. 3.

were built in specially excavated wells between the shafts. The shafts were similar to shafts described on contract No. 2. Excavated material was scaffolded out to a depth of 12 ft., after which a windlass mounted on a tripod hoisted out material in buckets. Excavation for the intermediate manholes was made in circular wells 4 ft. 8 in, in diameter, sheeted with 2 in. lumber secured in place by steel rings and material hoisted out by a windlass. No trouble was encountered in sinking these wells to a maximum depth of 60 ft.

Fig. 14. North Shore Sewer. 24 in. Tile Sewer in Tunnel, Milton Ave., Glencoe. Contract No. 3.

From the shafts, the mining was carried on continuously for the full length of the heading, the tunnel being timbered as the work advanced and track laid. Muck cars of capacity ½ cu. yd. were used and hoisted to the second landing of the head-house and muck dumped into wagons. As soon as the headings were completed, the tile was laid in a concrete cradle beginning at the far end of the heading and working back to the shaft. Tile were brought in one at a time on the dump cars, the sides of the car

being removed. All joints were calked with jute soaked in cement grout and plastered. The backfill was brought down the shaft in the muck cars and packed over the pipes as laid, the usual procedure being to lay about four lengths of pipe and then backfill. This section was in uniformly good, stiff blue clay and work was performed under a sub-contract.

A more permanent plant was used on this job than on the 36, 33 and 30 in. concrete sections. The head-house was a heavily timbered two-story affair, equipped with a 6 foot cage elevator. A dump track was laid from the second story out over a dumping trestle, under which the wagons could drive. Hoisting plant consisted of a double drum hoist operated by a 40 h. p. vertical boiler. A small blower was geared to the shaft of the idle drum to furnish

Fig. 15. North Shore Sewer. Portable Engineer's Field Office.

air for ventilation and operated as needed. No compressed air was used. At the completion of the work from one shaft, the boiler, hoist and head-house, all mounted on skids, were moved ahead to the next shaft by teams pulling with block and tackle from dead-men. Two days were required to move and re-assemble the plant.

For connecting local sewers, a cast-iron drop pipe was built, extending from the connecting sewer down to the 24 in. sewer and carried outside of the manhole. The drop pipes were encased in concrete. The work on the 18 and 12 in. tile sewers on the extreme end of the contract was carried on in a similar manner to that employed on the 36, 33 and 30 in. sections except that the

shafts were closer together. An average daily progress on the 24 in. tile in tunnel was 41 ft. or one foot per man per day, and is a very good record.

COST DATA.

Cost data to be of any value must be founded on a correct daily report on labor and a weekly or a monthly report on material.

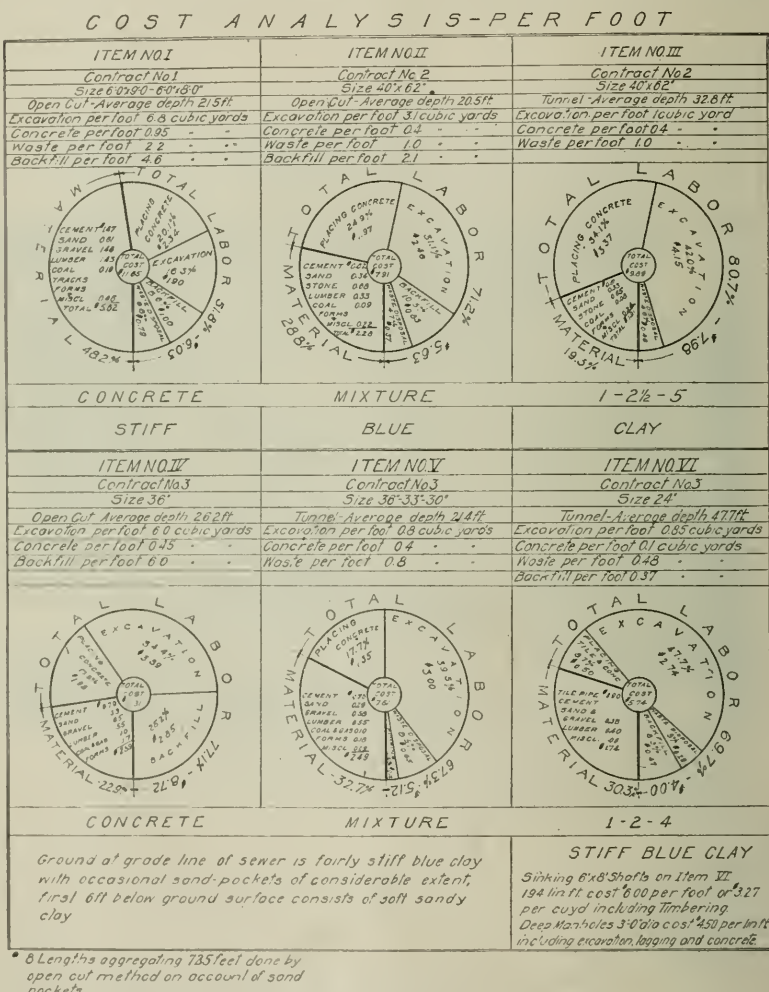

Fig. 16. North Shore Sewer. Cost Analysis.

The contract prices for material can usually be obtained from the contractor, and one sheet only need be made out for this, applying the unit prices to the monthly statement.

For the use of the Sanitary Division of the District a daily report for labor and progress of the work was devised, designed to fit either an open cut or a tunnel job. The distribution of hours is made at the time the form is filled in. The rate per hour need not be filled in daily, since this can be covered on one sheet showing the rates for the entire job. From these reports, a monthly tabulation is made, the rate per hour applied, and extensions made, reducing the whole to a money basis. At the end of the work, the

NORTH SHORE INTERCEPTING SEWER
COMPLETED JAN. 1st 1916.
GENERAL INFORMATION

Item	Size	Shape	Average depth	Length	Contract Price	Method used	Contract Number	Location	Contractor
I	6'-0"x9'-0"	Egg	feet 21.5	feet 10060	$15.00	Open Cut	1	Sheridan Rd	H. J. McNichols Co.
	6'-0"x8'-0"		21.5	4280	14.50	Open Cut	1	" "	
II	40"x62"		20.5	2940	8.10	Open Cut	2	Winnetka Ave	Marquette Construction Co.
III	40"x62"		32.8	3630	16.15	Tunnel	2	" "	
IV	36"	Ovoid	26.2	1112	11.00	Open Cut	3	Skokie Line	Nash Bro's.
V	36"		23.6	2431	11.00	Tunneled by Option of Contractor	3	" "	
	33"		20.2	8272	9.15		3	" "	
	30"		20.5	6423	8.85		3	" "	
VI	24"	Circular Tile	47.7	4195	10.00		3	Milton Ave	
	18"		23.5	2398	8.70		3	and other	
	12"		17.8	476	3.75		3	Streets	
	9"		20.0	123	3.80		3	in Glencoe	
				46340					

Note:—All sewers over 24" in diameter built of monolithic concrete, 24" and under built of vitrified tile laid in concrete cradle.

Cost of Materials			Cost of Blaw Steel Forms per foot of sewer	
Kind	Items I-II-III	Items IV-V-VI	Contract No.	
Cement	$1.19 per bbl.	$1.25 per bbl.	1	Open cut - 20¢ per ft.
Sand	$1.65 per cu. yd.	$1.70 per cu. yd.	2	Open cut - 18¢ per ft.
Gravel	$1.65 " " "	$1.70 " " "	2	Tunnel - 21¢ per ft.
Lumber	$22.00 per M.	$26.00 per M.	3	Tunnel - 18¢ per ft.
Coal	$3.50 per ton	$4.00 per ton		
24" Tile Pipe		90¢ per ft.		

Fig. 17. North Shore Sewer. General Information.

monthly statements are compiled, making a grand summary of the entire cost of labor and material, but showing a separation for the different parts composing the work. (See Fig. 26.)

From the data collected diagrams have been made showing the proportional costs for the different parts of the entire work. For the purpose of cost analysis the entire nine miles of sewer is divided into six items, each item shown being divided proportion-

ately for the different parts comprising that item. Comparison of the wheel diagram and the general information table shows that item 1 afforded a good margin of profit. This item was a well balanced job, that is, the labor and material about divide the circle in half. This proportion will generally show a good margin of profit on an open cut job. (See Figs. 16 and 17.)

Taking Item 2, also an open cut job, it will be seen that there is practically no profit and the proportion of labor to material is 71 per cent to 29 per cent, respectively, or entirely out of proportion.

Item 3 is in tunnel and shows a good margin of profit, with the labor of 81 per cent against material 19 per cent. This can also be called a well balanced job, as on tunnel work the labor should run considerably higher than on open cut, with a corresponding decrease for material on the proportional cost, or about 75 per cent for labor and 25 per cent for material.

Item 4 is the 1,100 feet of open cut above referred to and where this method was abandoned and tunnel substituted. It shows no profit, with the labor item at 77 per cent and material at 23 per cent and in contrast with this a reference to item 5 gives us the cost of the same sewer after the contractor changed his method of work from open cut to tunnel. The item shows the labor as 67 per cent and the material at 33 per cent. Comparison will show a profit. The 36, 33 and 30 in. sizes are grouped together under this item, as the work is all of the same character and very little difference was found in the actual amount of material used.

Item 6 completes the cost data for the North Shore sewer and is the 24 in. tile in tunnel. This is a well balanced diagram, with a corresponding margin of profit, with labor at 70 per cent and material at 30 per cent. Should the cost per cubic yard be desired on any of these items shown in the diagrams, it is only necessary to divide the cost of that item by the number of yards shown above the circle. In the lower left hand corner of the figure is given the cost of materials, together with the costs of the steel forms, reduced to a cost per linear foot of sewer. The cost diagrams do not include overhead charges, first cost of plant, depreciation, interest or bonding; they do, however, include all field expense, including the liability insurance on contractor's employees and superintendence. The entire sewer project, including the three contracts, was completed at a cost of $600,000 based on the contract prices.

With the aid of data similar to that contained in these tables, reinforced by current market quotations on labor and material, the writer has made estimates for similar kinds of sewer work, which frequently agree with a low bid within a range of from 3 to 13 per cent. In applying any data, a word of caution is necessary, since two jobs are seldom alike. In transferring the unit cost for work already performed to new estimates, due consideration must be made for differences in the local conditions, character of the soil,

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Abbott—Intercepting Sewer Construction.

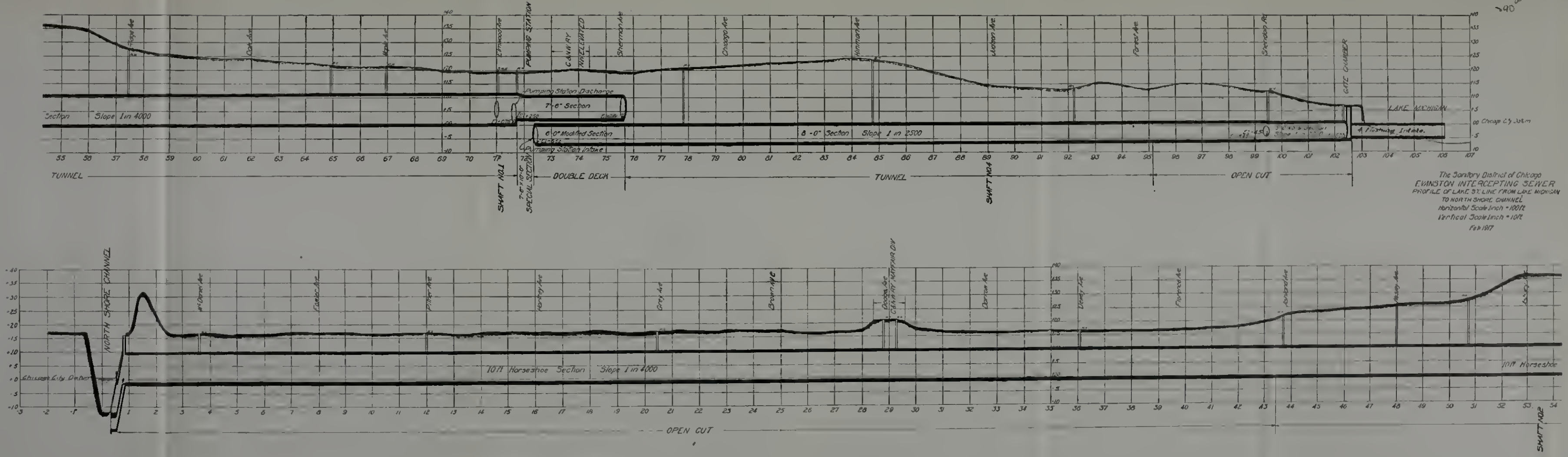

Fig. 18. Evanston Sewer. Lake Street Profile.

increased cost of labor, and the availability of standard types of machinery to handle the work.

The contractors for the different sections were as follows:

Contract No. 1—H. J. McNichols Company.

Contract No. 2—Marquette Construction Company.

Contract No. 3—Nash Brothers.

Sub-contractors on the 24 inch tile section in tunnel, Giblin & Peterson.

EVANSTON INTERCEPTING SEWER. (SEE FIG. 18.)

With the completion of the North Shore intercepting sewer all the sewage north of the Chicago River was diverted from the lake, with the exception of the sewage from the City of Evanston, which still enters the lake. For several years the construction of the intercepting sewer was discussed by the city council of Evanston and the board of trustees of the Sanitary District of Chicago. Various reports were made by the engineers of the city and district, covering many routes. After several deadlocks and a delay of a year or more an agreement finally was reached between the city council of Evanston and the Sanitary District, on the 29th of February, 1916, whereby the District undertook to build in the City of Evanston a complete intercepting sewer system to remove all the sewage from the lake, and to pick up certain sewers in the north end of Chicago, now entering the lake just south of Calvary Cemetery. In order to collect the sewage most advantageously and reduce the possibility of overflow in the lake a number of branch lines have been planned.

The main line of the Sanitary District sewer will be located in Lake St., running west from the corner of Elmwood Ave. with a diameter of ten feet and a slope of 1 in 4,000. This will receive by gravity the flow of the branch sewers from Elmwood Ave. and Custer Ave. as well as from Sherman and Orrington Aves. The outfall at the North Shore Channel on Lake St. consists of a double deck sewer section, extending down the bank of the channel from the ten foot sewer and discharging under water. The lower deck is a cast iron pipe, four feet in diameter, on which is imposed a modified horseshoe section, comprising the upper deck, the dry weather flow discharging through the lower tube. At the upper end of the outfall is placed a movable weir, counter weighted with a device set in the roof of the sewer.

A pumping station at the intersection of Elmwood Ave. and Lake St., electrically driven, will lift the sewage from the low level or shore line into the ten foot outfall. The shore line will be built in general along Sheridan Road extending from Howard St. on the south to Lake St., and from University Place on the north to Lake St. To flush the low level sewer on Lake St. an intake will be provided, four feet in diameter, to extend into Lake Michigan a distance of 300 ft. This intake pipe showing on the extreme right of profile will be supported on piles and protected by a crib work;

the outboard end will have a screen chamber and the connection with the six foot sewer will be made in a gate chamber, provided with a float well and shut-off valve.

The sizes of the sewers to be built range from six inches up to ten feet in diameter, the total length of the different sections aggregating about nine miles. All the sections are circular except the 10 ft. outfall and this is horseshoe shape. There are several crossings under railroads, water mains to be relocated, gas pipes and electric conduits to be moved and other miscellaneous work. The sewer system comprises also the line on Emerson St. from Ashland Ave. west. This line is designed to relieve the storm water discharge towards the lake and carry it into the North Shore Channel.

At the request of the City of Evanston, the surplus excavation amounting to over 75,000 cubic yards will be deposited along the Lake Front from University Place, south, inside the proposed shore line of the Evanston Park. The Sanitary District of Chicago has agreed to contribute $15,000 towards the cost of a sea-wall or bulkhead to protect this deposit from erosion. The sea-wall is being built by the City of Evanston with the Great Lake Dredge and Dock Co. as contractor. (See Fig. 19.)

Immediately following the agreement between the City of Evanston and the District two survey parties were put in the field and surveys covering the entire route were made, using the stadia method. The profiles were run with a Y level after completion of the stadia work. The surveys were plotted as a continuous map, the tracings made on 30 by 40 inch sheets on a scale of 1 inch to 20 feet, making two runs on each sheet, thus covering a stretch of about 1,400 feet per sheet. 111 four inch test borings were made by the District, spaced about 400 feet apart and data plotted on the profile for the contractors' information.

The contract for this work, comprising 91 items, was awarded September 7th, 1916, to the Nash-Dowdle Co. of Chicago. Shovel day with appropriate ceremonies was celebrated Sept. 23rd, 1916, at Custer Ave. and Mulford St. Actual work started Oct. 6th, 1916, at this point, building 1,300 feet of three foot sewer in open cut that fall, using a Parsons excavating machine for the excavation down to the water line; below this the work was done by hand. Sheeting was driven with a small portable steam hammer suspended from a boom attached to a small derrick, the steam supply being taken from the Parsons machine. A tractor gas engine backfilling machine fitted with caterpillar wheels made the backfill, dragging the dirt into the trench by means of a scraper operating from a boom.

Certain sections of this system were specified to be built in tunnel totaling 3,000 feet on the 6 and 10 foot sizes, later, and at the request of the City of Evanston the amount of tunnel was increased to 6,800 feet and corresponding decrease in the open cut. Most of the additional tunnel was in the business district. The contractor began installing plant for the tunnel sections on Nov.

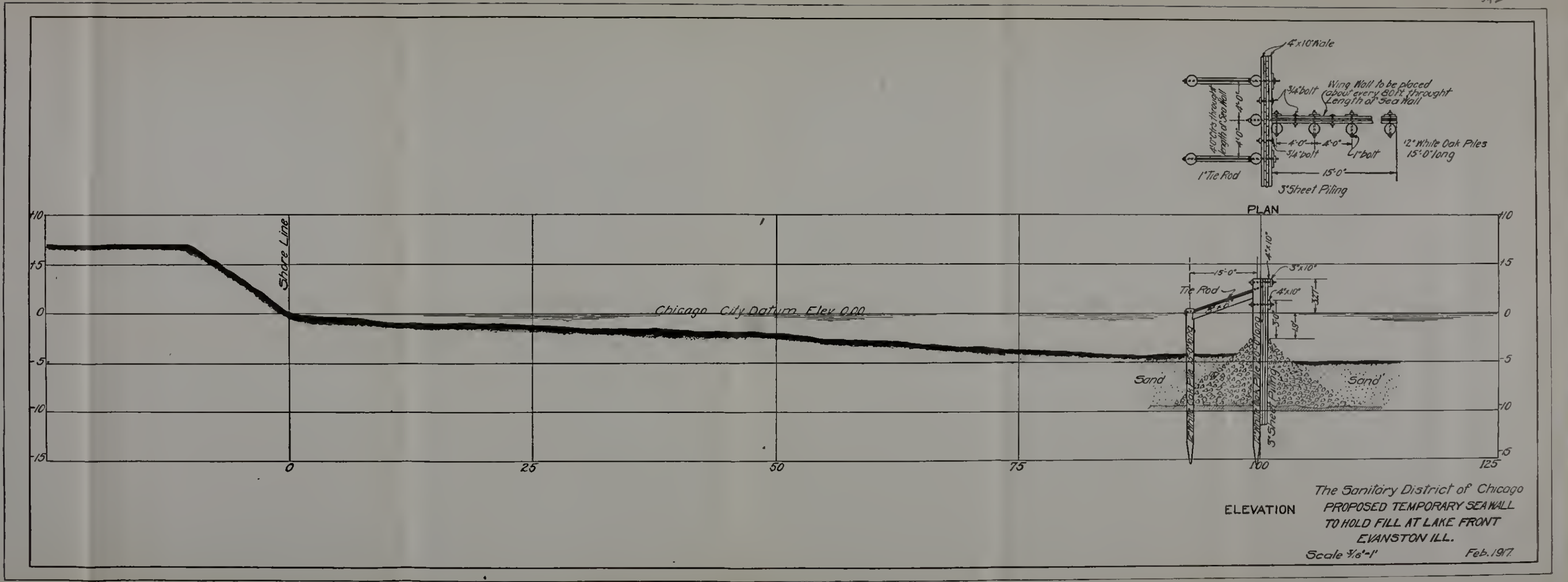

Fig. 19. Evanston Sewer. Sea Wall.

23rd, 1916, for the 6, 7½ and 10 foot tunnels on Lake St. and Elmwood Ave. Actual construction began on Feb. 16th, 1917, on the 10 foot horseshoe section. The time between these two dates, or a period of 70 days, was employed in installing power house machinery, sinking three shafts, building monkey or side drifts and putting in the air locks. The shafts, which are spaced about 1,800 feet apart, are offset from the main line 40 to 50 feet to give room for an air-lock, 14 feet long, and passing tracks for concrete

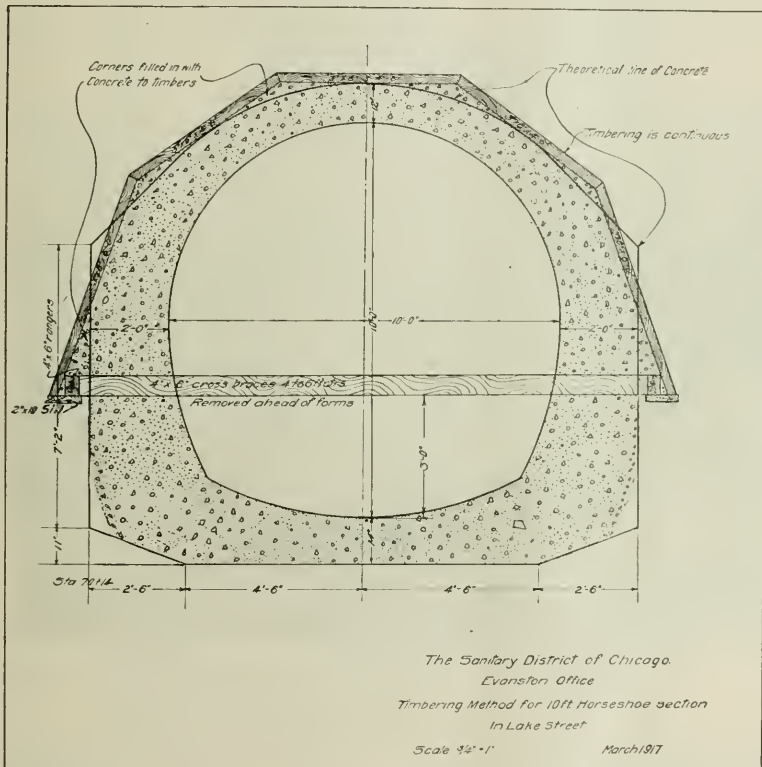

Fig. 20. Evanston Sewer. 10 ft. Outfall Sewer, Section Showing Timbering Method.

and muck cars. All shafts and monkey drifts are lined with concrete.

As the bottom of these sewers lay 7 to 17 feet below the ground water level and material was largely sand and mixed sand and clay, compressed air and timbering proved necessary. The timbering is almost continuous, consisting of 3x8 inch hard maple placed as fast as excavation is made. The foot of the crutches, in general, rest on the top of the good stiff clay; the open spacing between the

crutches varying from 2 to 16 inches according to the nature of the ground. Figure 20 shows the method of this timbering in the different sections. The cross braces are removed just prior to setting up the Blaw forms, but all other timbering is left in place.

The air pressure carried varies from 3 to 10 pounds per sq. in., according to the requirements in the different headings. Three headings lead from shaft 1, two headings from shaft 2 and two headings from shaft 4. The seven headings were all fed from one set of air compressors. As considerable air escaped from the pipe lines laid on the street surface, together with further loss through the sandy roof in the headings, the contractor closed down shaft

Fig. 21. Evanston Sewer. View of Shaft No. 1 and Power House, Elmwood Ave. and Lake St. Three Headings Lead from this Shaft.

No. 4 for about 30 days, replaced one of the small motors with one of 100 h. p. capacity and reopened the shaft, driving one heading only, or a total of 6 headings under way at present. As the cover over the roof on part of the work is as small as 7½ feet and ground is sandy, care is taken not to carry too much air pressure, as blow-outs might occur.

The compressors consist of one Sullivan high pressure machine with a capacity of 600 cu. ft. free air per minute, driven by a General Electric 100 h. p., 60 cycle, 3 phase, 720 r. p. m. motor, and one Clayton compressor of 635 cu. ft. capacity operated by a motor of similar type. This machine is also geared to a 45 h. p. gas engine for emergency use. There are also two small compressors

of 460 cu. ft. capacity driven by 30 h. p., 850 r. p. m. Northwestern Electric Co. motors. Part of this plant is kept in reserve. Power, to the extent of 270 h. p., is supplied by the Public Service Co. of Northern Illinois at an average cost of 1¾ cents per kilowatt hour. The elevators at the shafts are electrically operated. At shafts 2 and 4 by 8 h. p. motors and at shaft 1 by a 15 h. p. motor. Six-inch headers conduct the air from the compressors to receivers at 15

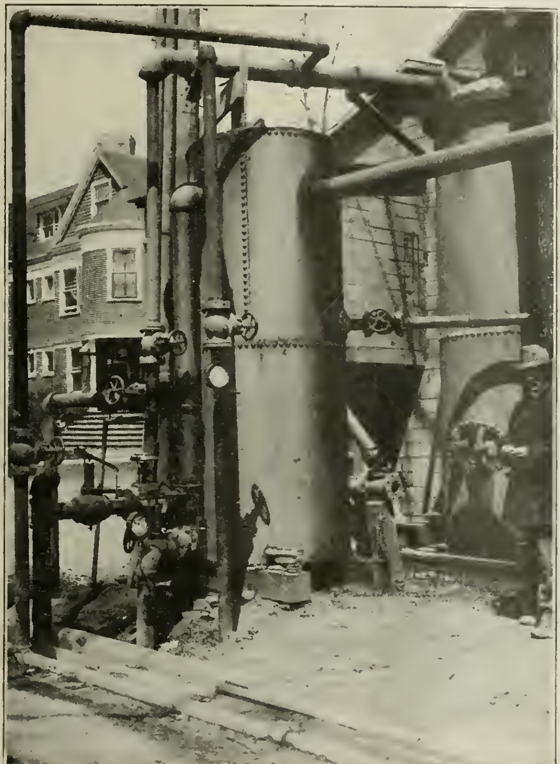

Fig. 22. Evanston Sewer. Air Receivers, Having Automatic Check Reducing Valves on Outlet Pipes Leading to Three Separate Shafts. Valves Maintain Even Pressure.

to 20 lbs. pressure. Three and four inch pipe lines leading from these receivers down the shaft and into the tunnel or along the street gutter to other shafts. On leaving the receivers, the air passes through automatic pressure reducing check valves, releasing the air from the receivers at the pressure required at the different shafts. (See Fig. 22.)

Work is carried on with three eight-hour shifts in each head-

ing, two shifts on the mining and one on the concreting. Concrete is mixed at the top of each shaft in Marsh-Capron mixers, capacity 21 feet of dry material, dumped into cars of ½ cu. yd. capacity, lowered on the elevator and passed through the air lock. The mixers are operated by 15 h. p. steam boilers. Mules are used for both concrete and muck cars as soon as the headings have been driven a few hundred feet from the shafts. These cars operate on a 14 inch gauge track.

Gravel and sand are delivered to the shafts by White motor trucks of 5 tons capacity, hauling ¾ of a mile from the unloading plant at the railroad siding, each truck making a round trip in

Fig. 23. Evanston Sewer. Material Bins for Sand and Gravel at Railroad Siding.

twenty minutes. Two trucks are used. One truck delivers about 120 cu. yds. of material to the work in eight hours and it is estimated that it performs the work of seven teams. At the railroad siding the contractor has installed a Bartlett drag-line derrick equipped with an Owen one yard grab-bucket, operating from a 50 foot boom. This machine unloads the sand and gravel from the cars or from a stock pile into three 25 ton elevated Sunbury material bins. The motor trucks drive beneath and receive the load through sliding doors operated by a lever. These trucks also handle coal, cement and mixed material. (See Fig. 23.)

Blaw steel forms are used throughout the work. On the tunnel sections they are of the knock-down type with 7 inch ship-channel

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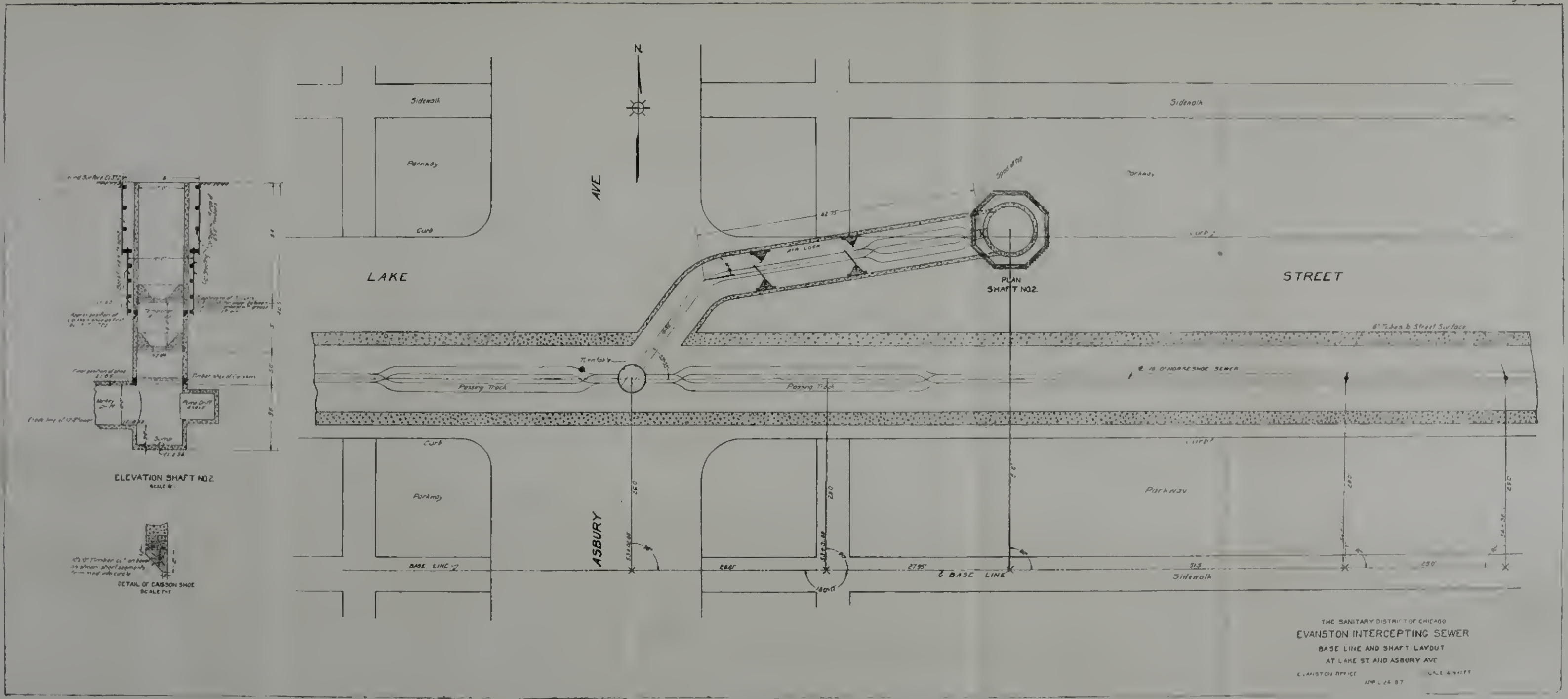

Fig. 24. Evanston Sewer. Shaft No. 2, Showing Temporary Air-Lock in Shaft.

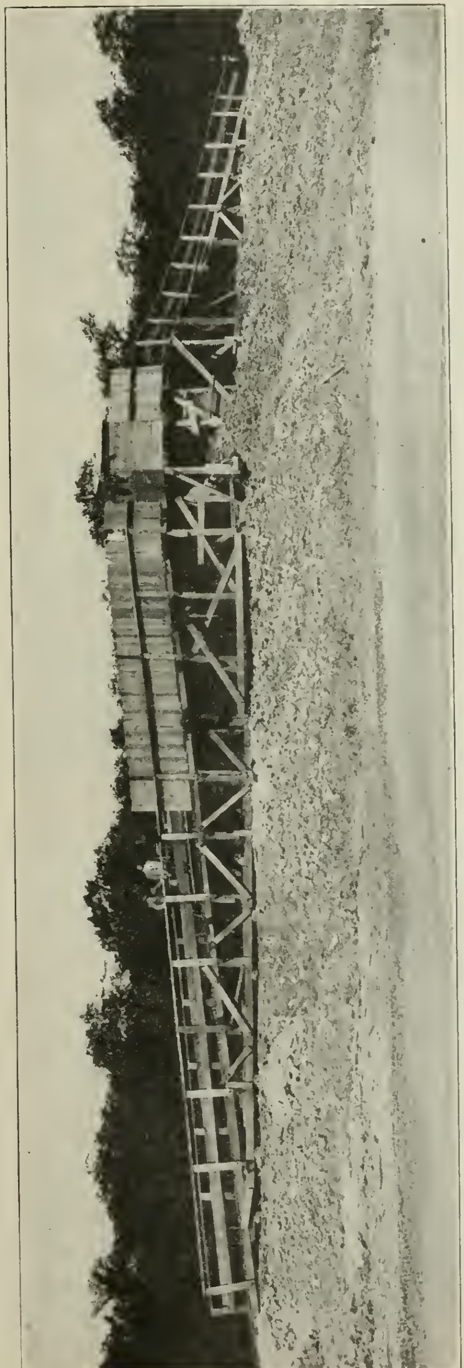

Fig. 25. Evanston Sewer. Movable Incline Trestle Dump for Depositing Spoil Along Lake Front Behind Sea Wall. Additional Ground Will be Converted into a Park. Incline is Mounted on House Rollers.

ribs spaced 4 feet on centers on the 10 foot section, and 5 foot centers on the 7½ and 6 foot sections. A total of 52 feet of form is used on the 10 foot tunnel section. The lagging plates for this section vary in width from 18 inches to 21 inches, thirteen plates, including the key plate, being used in one set-up. For the 10 foot open-cut work the forms are telescopic, a 25 foot unit being carried ahead with a traveler 21 feet long, running on T rails supported by cross timbers. The lower 15 inches of these forms is hinged and can be turned up, permitting the dropping of the arch to pass the form ahead. No form is to be used on the invert, the ribs being blocked and held in place at the bottom by 4 by 6 inch timbers butting against the cross timbers which carry the track for the traveler. One hundred and fifty feet of these forms are to be used on this section. On the smaller sized sewers in open cut half round forms are used made up in 5 foot sections, the collapsing being done by turnbuckles.

Considerable grouting is necessary over the roof of the tunnel to prevent loss of air. This grout consists of neat cement with sufficient water to make it fluid, and is forced through the crown of the sewer in 1½ inch pipes, previously set as the work progressed. The pressure is obtained by Deming 6 inch hand force-pumps, pumping from a tub into which the grout flows from a 3½ by 6 foot mixing-box fitted with a screen at outlet. If there are considerable voids to be filled, bran or sawdust is mixed with the grout, the proportion being one of cement to two of either material. This grout is forced into the sand and into voids between the roof timbers, penetrating to a considerable extent along the line of the sewer. Generally, in sandy ground, the pipes are placed in the roof 50 to 100 feet apart and if more are needed later the roof is drilled and pipes placed.

On account of the shafts being offset from the main line of the sewer, 4 inch or 6 inch tubes were sunk from the street surface on the center line of the work for the purpose of checking the alignment. In all 13 of these tubes were put in, having plugs at the top, the lower end being closed with wooden plugs plastered over with cement. When conditions were such that the air pressure could be taken off at the different shafts, the tubes were opened up and heavy plumb-bobs dropped through, checking the line. The grade was also checked through these openings. Very little discrepancy has been found between these lines and the lines as carried down the shafts and through the monkey drifts.

Some difficulty was encountered in sinking shaft No. 2 located at Lake St. and Asbury Ave. This shaft is 40 feet in depth located in a sand ridge. As slight progress was made on account of the water below a depth of 20 feet, the contractor decided to sink it as a caisson. A timber shoe was put under the concrete at the 20 foot level and the shell sunk a further distance of 10½ feet, or level with the top of the monkey drift. The concrete lining was then extended up to the street surface. In sinking the caisson a maxi-

mum weight of 40 tons of sand was applied. This is equivalent to a frictional resistance on the surface of the caisson which was below the sheeting of 280 lbs. per sq. ft. After the final position had been reached a temporary air-lock was installed in the shaft,

Form No 142

TUNNEL

THE SANITARY DISTRICT OF CHICAGO
ENGINEERING DEPARTMENT—SEWER CONSTRUCTION

DAILY LABOR REPORT

Fig. 26

DATE Apr. 24 1917

CONTRACT EVANSTON SEWERS

WEATHER Rainy - Cool

CONTRACTOR NASH-DOWDLE CO.

AVERAGE No. EMPLOYED 231

EMPLOYEES	No.	TOTAL HOURS	Excavation: Shaft No 1-2-4	Backfill	Waste Disposal	Concrete: Shaft No 1-2-4	Forms	Reinforcing	Sheeting or Timbering	Material	Pumping	Plant	Miscellaneous	Extra Work
Superintendent	1	8										8		
Asst. Supt. Tony	1	8			4					4				
~~Civil Engineers~~ Master Mechanic	1	8										8		
Report Clerk														
Chief Timekeeper	1	8										8		
Timekeepers	3	24										24		
Material Clerks														
Foremen	9	72	48			24								
Asst. Foremen	1	8				8								
Heading "														
Concrete "														
Powerhouse Men	3	24										24		
Machinists, etc.	4	32										32		
~~Tool Sharpeners~~ MINERS	37	296	296											
Muckers	28	224	224											
Timbermen														
Concreters Below	19	152				152								
" on Top														
Laborers Below	13	104	16			88								
" on Top	28	224	104		16	104								
Elevatormen	9	72	48			24								
Skinners	9	72	48			24								
Airlock Men / Pumpmen	12	96	72			24								
Utility Men	9	72	16			16				24			16	
Teams	22	176	144		8					16			8	
Shovel Engineer	1	8								8				
Cranemen														
Shovel Firemen														
Bottommen														
Formmen														
Carpenters	1	8										8		
Watchmen	3	24										24		
Waterboys														
Mixer Engrs	3	24				24								
Auto Trucks	2	16								8		8		
Car Pushers	7	56	56											
Plasterer	4	32										32		

REMARKS

Shaft No. 1 { West Heading 66+96; South Heading 2+88; North Heading 1+30 }

NOTE—Mail form daily, including Sunday, while work is in progress. Following a suspension of work, give date of suspension and resumption on next report.

WORK DONE TO DATE

		West Heading	East Heading
Shaft No. 2 Excavation	to Sta.	52+59	53+56
Concrete { Invert / Arch	" "	Same	Same
Shaft No. 4 Excavation	to Sta.	West Heading 82+44	East Heading 95+23
Concrete { Invert / Arch	" "	Same	Same

Respectfully submitted,

Fig. 26. Evanston Sewer. Force Report.

as it was necessary to have air pressure for the completion of the shaft, sump and monkey drift. Just prior to the installation of the permanent lock, the temporary lock was removed. The location of the tubes for the alignment can be seen at the right hand side of figure 24. Originally these tubes were to be adjacent to the junc-

tion of the monkey drift and the main line, but the contractor changed his plans and reversed the direction of the monkey drift after the tubes were sunk; however, after passing through three angles and about 200 feet in distance the survey as carried down

Evanston Sewers
Tunnel Section
Average Force and Output per 24-Hour Day
3 Shafts — 6 Headings

Force

On Top	In Tunnel
1 Superintendent	1 Asst. Superintendent
1 Civil Engineer	56 Miners
4 Material Men	30 Muckers
2 Timekeepers	4 Plasterers
1 Clerk	4 Laborers
3 Mixer Engineers	12 Skinners
3 Power House Men	9 Air-lock Tenders
14 Concreters	2 Pumpmen
5 Dumpmen	9 Elevator Men
13 Topmen	9 Foremen
2 Utility Men	
1 Machinists	
1 Shovel Engineer	
1 Master Mechanic	
1 Blacksmith	
2 Watchmen	
55	136

Total Men, 191.

Additional:
19 Teams on Waste Disposal.
11 Mules in Tunnel.
2 - 7½ ton Trucks on Material.
1 - 1½ " " Miscl. Work.

Output

Size	Feet Built	Headings	Excavation Cu. Yd.	Concrete Cu. Yd.
10 ft.	28	3	156	70.0
7½	10	1	29	13.2
6	30	2	54	26.4
Totals	68	6	239	109.6

Note Force and progress taken from report of May 25, 1917.

Fig. 27. Evanston Sewer. Average Working Force.

the shaft split the tubes in half, the check from the street surface has not yet been made.

Up to June 1st most of the work done has been in tunnel, but plant is now being stalled for the open cut. The 10 foot section on Lake St. and the 4½ foot section on Emerson St. are to be handled

in a similar manner to that on Sheridan Road described. On the Emerson St. line the shovel will excavate an existing 5 foot brick sewer as work progresses, building the new sewer with a slope in the opposite direction, as the old sewer is too high for good tributary drainage. On Lake St. the sewer will pass under and receive the excess flood water of a number of small sewers on the north and south streets between Elmwood Ave. and the North Shore Channel. At three points on the Lake Shore line, spillways will be left, maintaining the existing sewers between the interceptor and the lake to act as cloud-burst relief sewers. The crest of these overflow weirs is to be set at elevation plus 4. These spillways are to be located at the connection with the 6 foot Emerson St. and the 40 inch Main St. sewers, also at the south end of Calvary Cemetery.

Spoil is taken to the dump at the lake front by teams and dumped along the spoil area previously mentioned. At this place, a traveling incline has been built, the teams approaching from the south and mounting the 12% grade with the aid of a snatch team, dumping the load through a trap door at the top. An inclined chute leads from this trap door towards the lake. The material is deposited very uniformly. The whole incline is mounted on house rollers and is moved in either direction by a winch located on the lower frame of the incline and having a wire cable attached to a dead-man. (See Fig. 25.)

Nothing can be presented at this time relative to the tabulated costs on this tunnel work, but the number of men carried by the contractor and the progress made with this force can be shown. This tabulation shows an average daily progress of 68 feet on the three sizes with a force of 191 men, not including teams. This is equivalent to 0.35 of one foot per man per day (see Fig. 27). The tunnel work on this contract is under the general supervision of Mr. George W. Jackson, acting for the contractor.

This entire contract, exclusive of the pumping station, amounts to $900,000 and was 20 per cent completed on June 1st.

The construction work described in this paper was carried on under the supervision of the writer as Assistant Engineer for the Sanitary District of Chicago, under the direction of Mr. Langdon Pearse, Division Engineer, and Mr. George M. Wisner, Chief Engineer. Able assistance in the preparation of this paper has been given by Mr. L. B. Barker, who has been connected with the work described as Resident Engineer.

DISCUSSION.

Langdon Pearse, M. W. S. E.: The work was carried out along the lines indicated. My purpose is to point one or two matters of interest to engineers, particularly in preliminary work—particularly the matter of borings. The ground along the Skokie marsh was of a variable nature, full of sand and gravel pockets, which were a source of trouble. In this section of the work 75 feet of the sewer settled about 2 feet in the course of two years. It has

since been necessary, in order to secure a proper foundation, to drive 12-foot piles underneath this sewer. The original work was put on a plank or floating foundation. The location and character of these sand pockets could not be determined by the borings that were made, although the borings were made about 800 or 1,000 feet apart. The contractor was very lucky in that he could change his method of work so completely along the Skokie from open cut to tunnel and come out practically even or possibly with some slight profit. This showed good management. At times he had difficulty in holding the ground inside the tunnel. The timber frames were sometimes squeezed in so that jacks were used to push the timbering back in order to get the proper section for the concrete. The excavation of the two main tunnels, that is, the one on Indian Hill and on the north at Milton Avenue, was particularly firm and would stand without timber, if the excavation was followed immediately by concreting. Owing to placing 24 inch tile pipe in Milton Avenue, the excavation was timbered, since the pipe could not be placed in the tunnel until the entire section was excavated between shafts.

In the Evanston work the general plan has been somewhat changed, in particular in extending the amount of tunnel, in order to protect the use of the streets in the City of Evanston. The Nash-Dowdle Co. and George W. Jackson have been very successful so far in obtaining good results, without any large loss of air. The tunneling method has been of benefit to the city, particularly on Sherman Avenue, one of the main business streets. The street railroad tracks have been kept open. The finish on the tunnel is good. The work done would seem to indicate that where plastering is carried out in compressed air it was much better than in open cut. If the members here who are interested in tunnel and sewer work will visit the job at their leisure and see what is being done they will be well repaid. The use of steel forms seems to cause one slight difficulty which is very hard to overcome, as you will notice from the pictures. A slight amount of concrete oozes in between the joints. All forms on the North Shore were Blaw forms, although some wooden forms were used along the Skokie. The invert was the principal difficulty, on account of the egg section, which is hard to handle. The best success was had by putting in concrete blocks in the dish first and the rest of the invert and arch with Blaw forms. That, of course, could not be done in tunnel work.

We have been trying to keep our records in shape as indicated by Mr. Abbott and have met with some success. The cost analysis involves a constant checking. I think we have secured good results without imposing very much additional labor on any of the men, and we are certainly indebted to all of our men on the work who helped Mr. Abbott in obtaining the material upon which this paper is based.

L. K. Sherman, M. W. S. E.: Mr. Abbott's paper is a very valuable compilation as a matter of record and cost data. It is very difficult, as Mr. Pearse has pointed out, to determine absolutely

what is underground, what the contractor will strike. One of the easiest ways for a contractor to go broke is to gamble on the character of material in a sewer, and when you compare costs data such as Mr. Abbott has presented, we must carefully bear in mind the difference in soil conditions which will offset absolutely any of the other features—labor, material or anything else that may come in.

Several years ago when I was with the Sanitary District, these various schemes for solving sewage disposal problems on North Shore villages came up. Among other plans it was proposed to dredge out the north branch of the Chicago River from up near Lake County. There were plans for sewage disposal plants for all these different towns. Then there was another scheme of running the sewer down along the edge of the lake below the bluffs at the edge of the ravines. Also a project for cutting a tunnel through at the upper end of the Sanitary District territory near Lake County and pumping water through the tunnel to flush out the north branch of the Chicago River. All of those schemes were thought over.

J. W. Mabbs, M. W. S. E.*:* I would like to ask how many of the North Shore suburbs can be taken into this system as laid out.

Mr. Abbott: There are four villages in the present system—Wilmette, Kenilworth, Winnetka and Glencoe. The line on Sheridan Road was designed to take in more territory to the north, but that is a matter for future consideration, being a district which lies north of the Sanitary District of Chicago. The northern line of Glencoe is the limit of the Chicago Sanitary District.

Mr. Mabbs: How many pumping stations do you have to have in that district? Do you have to handle the sewage more than once?

Mr. Abbott: The present North Shore system has no pumping station whatever. If it were extended up several miles north it would have to have pumpage, somewhere along the line.

Mr. Mabbs: Will all of this sewage run into the drainage cut by gravity and without any power?

Mr. Abbott: The outlet sewer discharges into the North Shore channel, which flows into the main channel without any pumping. There is pumping on the Evanston intercepting sewer on account of flat grades, flat surface of ground and long lines of sewer, and it is necessary to have pumps. No pumps, however, on the North Shore system.

Mr. Mabbs: In the case of the suburbs further north, if they were brought into this system, would they have to be pumped?

Mr. Abbott: If the system were extended far enough north as, for instance, Lake Forest, it would have to be pumped.

G. C. D. Lenth, M. W. S. E.: I think it would be of interest in general to the Western Society of Engineers to have a diagram showing the method of timber framing which is ordinarily used to support the 70-ton steam shovel on the work which he described in Glencoe and in the north section of the North Shore towns.

Another item that occurred to me that I would like to have some further light on is the question of the Milton Avenue sewer

where the sewer was constructed in tunnel of 24-inch tile pipe. Was timbering left in place in that case, and if so what was the method of timbering?

Another question that occurred to me was in the case of the Evanston intercepting sewer in regard to the contractor's plant. Mr. Abbott mentioned that the Public Service Company of Northern Illinois is furnishing electric power for the air compressors. Is there any standby current? Does the Sanitary District contemplate any standby current for the proposed Evanston sewage pumping station, which I understood is also to be operated by the Sanitary District power?

Mr. Sherman: Was this sewer running up to Lake County designed large enough to accommodate sewage from Waukegan district in Lake County, and if so, was that done by any positive agreement with Lake County?

B. E. Grant, M. W. S. E.: The Sanitary District has built many large sewers of concrete. I understand in some cases they have taken alternative bids on brick sewers. Can you give some information on the comparative prices received on brick and concrete sewers?

Mr. Abbott: With reference to the questions of Mr. Lenth, about timbers supporting the shovel, a sketch can be made showing that 16 by 16 inch timbers were used, 6 or 8 timbers altogether spanning the trench, resting on house rollers. The concrete mixer spanned the trench in a similar manner. In the 24-inch tile sewer in Glencoe in Milton Avenue, the timbering, or very nearly all of it, was left in. Only the part was removed that could be removed without disturbing the work. Dimensions of the tunnel are 4½ feet high, and 4¼ or 4 feet horizontal, just big enough for men to work in to transport their 24-inch pipe, and make the excavation.

In regard to the power for the Evanston pumping station, I believe it is the intention of the district to use their own power. There will be no standby as far as I know. There were overflows left along the lake front at Evanston. If there were a cloudburst there would be no more damage done than at present, since the sewers are not at present adequate to take all the storm flow. The overflows in the lake will relieve the situation and make the condition better than it now is.

In regard to the power now being used by the contractor, the Public Service Co. lines are connected with the Commonwealth Edison Co. so that they can draw on either power. There is very little chance of a fall-down. Since the work was started there was only a very slight stoppage of a very few minutes. The electric power was in use again before they could put the gas engine in service.

Mr. Lenth: You have a gas engine as a standby if the electric power falls down?

Mr. Abbott: Yes, but it has never been used.

In regard to extension of the sewer north to Waukegan, there will be no action taken whatever by the Sanitary District.

In regard to alternative bids taken for monolithic concrete and brick, bids on Contracts No. 1 and No. 2 on the North Shore sewer were taken that way, one for brick, one for concrete and one for concrete segmental blocks. Brick runs 10 per cent and segmental blocks run 20 per cent over concrete. We have other sewers where bids were taken in other portions of the Sanitary District where about the same ratio prevailed.

THE METHOD OF THE ELLIPSE OF ELASTICITY AND ITS APPLICATION TO CONTINUOUS ARCHES ON ELASTIC PIERS

By S. Moreell, Jr.

Presented April 30, 1917.

This paper gives an outline and explains the application of a complete graphical method for finding the stresses in statically indeterminate structures, including continuous structures resting on elastic supports. The method is applied primarily to arches, but it may readily be extended to include other statically indeterminate structures. It is easily applied and is comparatively rapid. The method as applied to single arch spans was first treated in the English language by A. C. Janni, in a paper presented before the Western Society of Engineers, in May, 1913. Most of the definitions and general relations given in the first part of this paper have been taken from that paper. Parts of this paper are also due to Professor W. Ritter, who originated the method. The application of the method is fully given in the fourth volume of Professor Ritter's "Anwendungen der Graphischen Statik." In the 1903 volume of the French technical paper "Genie Civil," Professor H. Lossier has presented a detailed proof of the method as applied to continuous arches, of which application Professor Ritter is also the originator. The greater part of the data in Part III of this paper was taken from Professor Lossier's paper. It is intended in this paper to give such proofs as are deemed requisite to an understanding of the theory and its application to a single unsymmetrical arch on fixed supports and to continuous arches on elastic supports. It is believed that the treatment of the subject is sufficiently broad to enable American Engineers to obtain a working knowledge of the method. The subject will be treated in three parts as follows:

Part I. Definitions and General Relations.

Part II. Application of Method to a Single Unsymmetrical Arch on Fixed Supports.

Part III. Application of Method to Continuous Arches on Elastic Supports.

The accompanying photograph shows a continuous arch structure on comparatively tall and slender elastic piers, designed by the Watson Engineering Company of Cleveland. It is of the type to

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Bridge Designing Engineer with City of Chicago.

which the method of the ellipse is applicable with resulting economy in the labor of design and in the use of materials.

PART I.

DEFINITIONS AND GENERAL RELATIONS.

1. *Elastic Weight of an Elementary Subdivision of Arch.*

If we consider a subdivision of an elastic arch rib AC, such as the voussoir AB (Fig. 1) to be free at end A and fixed at B and to have a length ds, then the elastic weight of the subdivision AB is defined by $\frac{ds}{EI}$, where E is the modulus of elasticity of the material and I is the moment of inertia of the cross-section of the voussoir, which is assumed constant.

2. *Semi Axes of the Ellipse of Elasticity of Voussoir.*

It will be (see Section 11) demonstrated that the measure of resistance to deformation of the element AB, from bending and direct stresses can be represented by an ellipse whose center coincides with the center of the element and whose radius (semi-diameter of the ellipse) perpendicular to the axis of the element is given by

$$r_1 = \sqrt{\frac{I}{A}} \qquad \text{.......................(1)}$$

in which I is the moment of inertia of the cross section of the element (assumed constant) and A is the cross section.

The length of the semi-axis of the ellipse which lies in the axis AB of the element is shown to be,

$$r_2 = ds \sqrt{\frac{1}{12}} \qquad \text{—— } \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equations 1 and 2 are developed on the supposition that bending moment and direct stress only act on the piece, distortions due to shear being assumed negligible in arches.

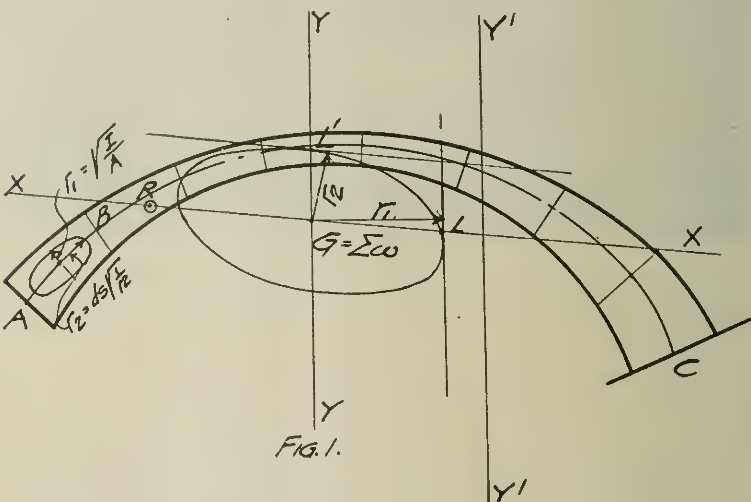

FIG. 1.

The ellipse having the semi-diameter given by equations (1) and (2) is called the ellipse of elasticity of the element AB. Its elastic weight is the same as that defined above and is $\dfrac{ds}{EI}$, which will hereafter be denoted by w.

3. *Elastic Weight of Free End of Arch.*

Assuming the arch AC. (Fig. 1) to be free at end A and rigidly fixed at C, that is, a cantilever support for applied loading, the elastic weight of the free end is defined as the sum of the elastic weights of the elements of equal length into which the arch axis is subdivided. That is, if G be taken to represent this total elastic weight, then

$$G = \Sigma \frac{ds}{EI} \Sigma w \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

4. *Ellipse of Elasticity of Free End A.*

It will be shown (see Section 11) that the resistance to deformation of the entire arch AC may be represented by an ellipse whose elastic weight is given by Σw, as noted above. The center of this ellipse is the center of gravity of the elastic weights of all the elements into which the arch is subdivided. In Fig. 1, this center is shown at point G, and it is found by the ordinary calculation, or by the graphical construction for finding the center of gravity of a system of forces. The forces here considered are the elastic weights of the different elements calculated according to the formula given above.

5. *Antipole and Antipolar with Respect to a Given Ellipse.*

From the theorems of projective geometry, we know that there is a fixed relation between a given ellipse, a given line, and a fixed point, which point is called the antipole of the line with respect to the ellipse.

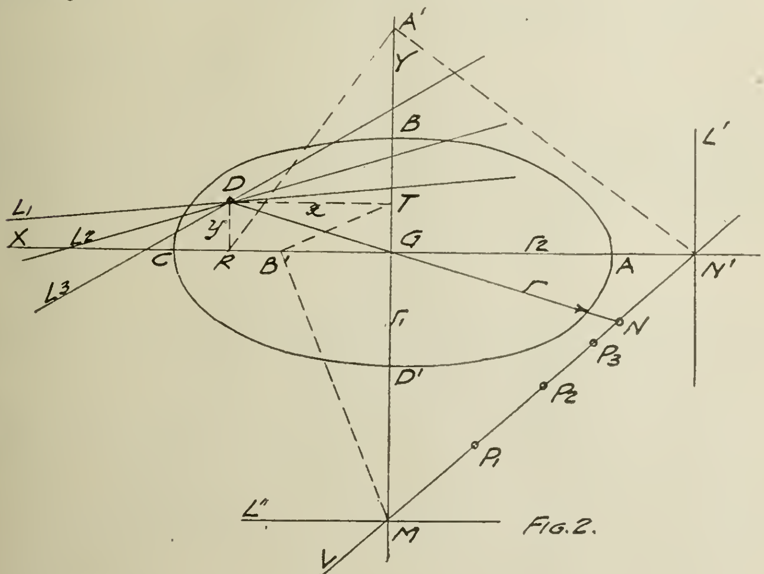

FIG. 2.

This relation (Fig. 2) is given by the proportion

$$DG : r : : r : GN,$$

$$\text{or, } DG = \frac{r^2}{GN} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where point D is the antipole, L is the given line, called the antipolar, and r is the semi-diameter of the ellipse measured on line DN, the center of the ellipse being at the given point G. Equation 4 states that r is the mean proportional between DG and GN.

The co-ordinates of point D, taking G as the origin and assuming vertical and horizontal axes of co-ordinates through G, are (see Fig. 2) given by

$$y = \frac{r_1^2}{GM} \quad \text{.......................................(5)}$$

$$x = \frac{r_2^2}{GN} \quad \text{.......................................(6)}$$

These equations which are similar to equation (4), state that r_1 is the mean proportional between y and GM; also that r_2 is in like relation to x and GN'.

It will be seen that if the given antipolar L' is a line parallel to the axis Y, intersecting the axis X at N', the antipole will be on the axis X, at a distance given by

$$x = \frac{r_2^2}{GN'}$$

Then y would be given by the equation,

$$y = \frac{r_1^2}{GM}$$

in which GM is infinitely large, since M lies at the intersection of two parallel lines. Thus y in this case is zero. Similarly, if the antipolar is parallel to the axis of X and meets the Y-axis at M, the antipole lies on Y at a distance from G given by the equation,

$$y = \frac{r_1^2}{GM}$$

To obtain the position of the antipole graphically, the procedure is as follows: It is assumed, as above, that the line L and the ellipse G with its diameters are given.

With point G as a center, describe an arc with radius r_2, cutting the vertical axis of the ellipse at A'. With the same center and the radius r_1 describe an arc cutting the horizontal axis of the ellipse at B'. Join B' to M and A' to N'. At A' erect a perpendicular to A' N' and at R, where the perpendicular cuts the X-axis, erect the vertical y. At B' erect a perpendicular to B' M and at T, where this perpendicular cuts the Y-axis, draw the horizontal x. The intersection of the lines x and y gives the antipole D. If the antipole D is given and it is required to find the position of L, the antipolar, it is merely necessary to reverse the order of construction

While the above relation between a given line, a given ellipse and a fixed point is a purely geometrical one, it becomes of importance, in the method at hand, when the line represents an axis about which we are taking the moments of elastic weights of the elements of an arch rib, or if the line represents a force which is acting on the ellipse, that is, upon the arch element represented by the ellipse. When the line represents an axis of moments of elastic weights the

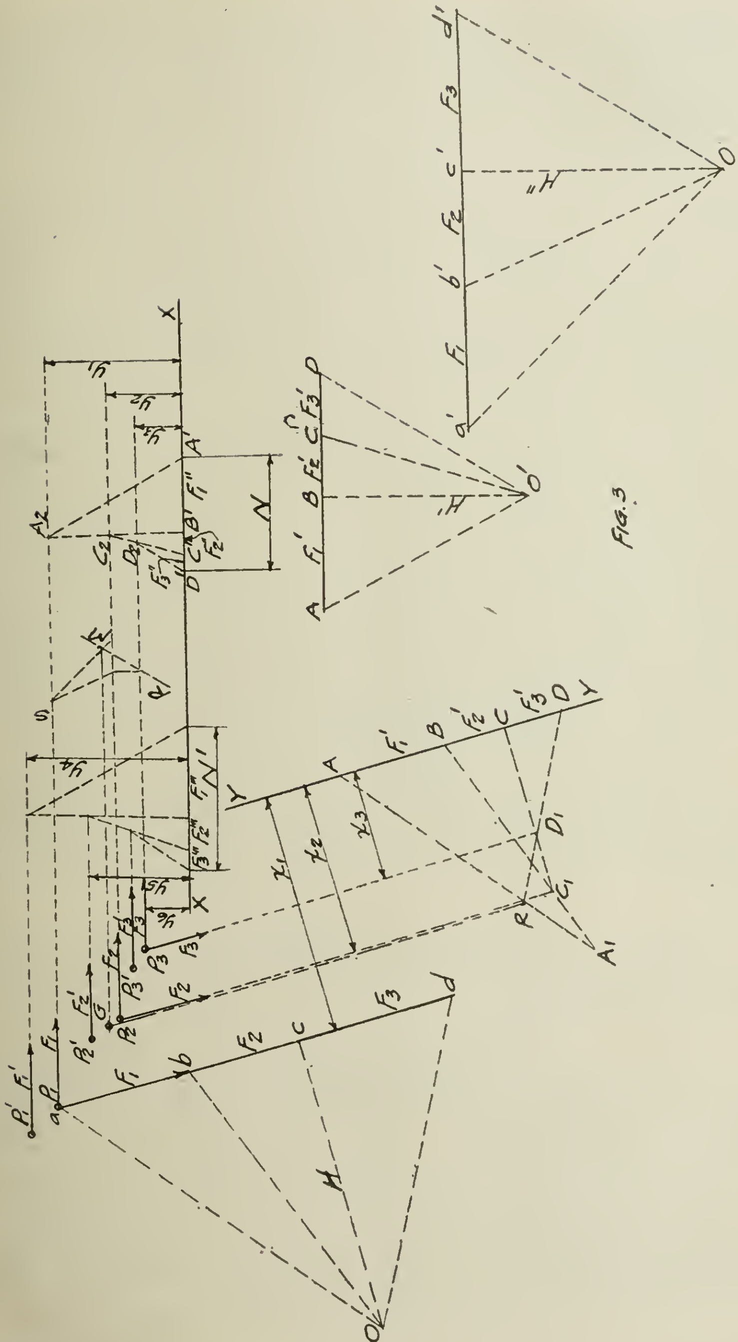

FIG. 3

antipole of the line with respect to any ellipse will be shown (see Section 11) to be the point of application of the *moment of the elastic weight of this ellipse about the line.* Or, if the line represents a force acting on the arch element represented by the ellipse, the antipole will be shown to be *the center about which the center of the ellipse will rotate* when acted upon by this force.

In the theory of projective geometry it is shown that for every position of a point P, (Fig. 2), as P_1, P_2 or P_3 on a straight line L, there is a corresponding position of a line L_1, L_2 and L_3, all passing through the same point D, in such a manner that D is the antipole of the line L, and P_1, P_2 and P_3 are respectively the antipoles of L_1, L_2 and L_3. That is to say, if the point P_1 generates the line L, and the axes of the ellipse G are assumed to remain fixed in position, then the line L_1 will rotate (with the motion of P_1) about point D as a center; where D is the antipole of line L with respect to ellipse G. Now assume that the line L_1 is held fixed in position while the point P_1 generates the line L. Then it follows, in order to satisfy the condition that D shall be the antipole of line L with respect to ellipse G, that the center G must rotate about point D as a center as point P_1 generates the line L. This is equivalent to the statement given above that a force acting along the antipolar L will cause the center G to rotate about the antipole D. Also, it follows that any moment or torsion applied at D will cause the ellipse G to rotate about D. In other words, the antipole is the center of gravity or point of application of a moment on G; or, as will be shown in Section 11, we might say that the point D is the point of application of the moment of the elastic weight G about line L.

6. *Product of Inertia and Relative Center.*

If (see Fig. 3) we consider a system of forces F_1, F_2, F_3, an axis Y-Y parallel to the direction of these forces, and an axis X-X in any arbitrarily chosen direction, then the product of inertia of these forces with respect to the two axes Y-Y and X-X is defined by

$$F_1\,x_1\,y_1 + F_2\,x_2\,y_2 + F_3\,x_3\,y_3$$

If axes X-X and Y-Y both happen to lie on Y-Y the product of inertia of the forces becomes their moment of inertia with respect to Y-Y, that is,

$$F_1 y_1^2 + F_2 y_2^2 + F_3 y_3^2$$

If we consider the moments of the forces F_1, F_2 and F_3 about Y-Y as a new set of forces applied at the same points P_1, P_2 and P_3 the center of gravity of this new set of forces is called the *"Center Relative to the Axis Y Y."*

The "Product of Inertia," "Moment of Inertia" or "Relative Center" can all be found graphically by the following construction:

In Fig. 3 consider the three forces F_1, F_2 and F_3 applied at points P_1, P_2 and P_3 and acting in the direction indicated. To find the moment of the forces with respect to any line Y-Y construct the force polygon $O\ a\ d$, as shown, with the arbitrary pole distance H.

Then if the lines A_1A, A_1B, C_1C and D_1D are drawn parallel respectively to the rays Oa, Ob, Oc, and Od the intercepts F_1', F_2' and F_3' will be respectively proportional to the moments of F_1, F_2 and F_3 about line Y-Y. The moments will be equal to $H \times F_1'$, $H \times F_2'$ and $H \times F_3'$, in which H is measured in the scale selected

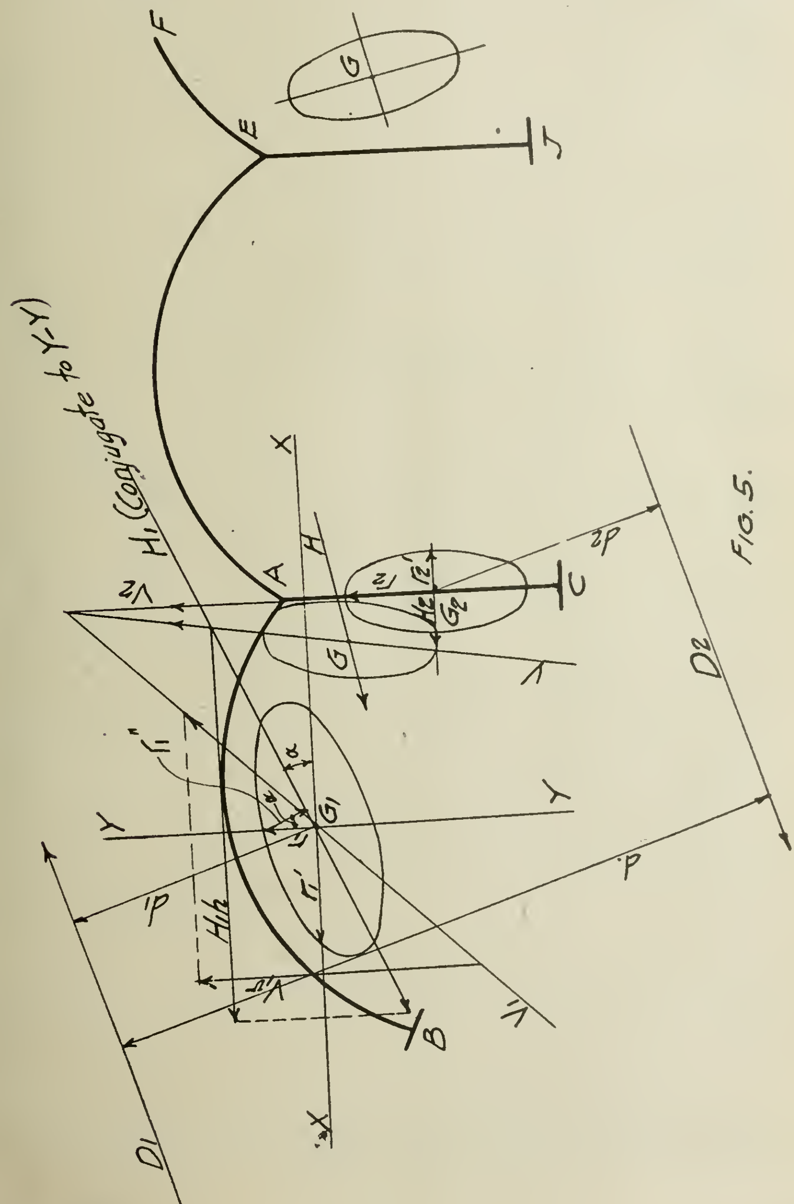

FIG. 5.

for distances, and F_1, F_2 and F_3 are measured in the scale selected for forces.

Let us now consider another arbitrary axis X-X and, applying F_1', F_2' and F_3' as forces in the direction X-X, at points P_1, P_2 and P_3, respectively, find the moments of these forces with respect to axis X-X. For this purpose we construct force polygon $A\ O'\ D$ with forces F_1', F_2' and F_3' and the arbitrary pole distance H'. Then if lines A_2A', A_2B', C_2C' and D_2D' be drawn parallel respectively to rays AO', BO', CO' and DO' the intercepts F_1'', F_2'' and F_3'' will be proportional to the moments of forces F_1', F_2' and F_3' about axis X-X. These intercepts will also be proportional to what is defined as the "Product of Inertia" of forces F_1, F_2 and F_3 with respect to axes Y-Y and X-X. The actual value of the product of inertia for any one of the forces, as F_1, will be given $F_1'' \times H \times H'$, in which F_1'' is measured in the scale selected for forces and H and H' in the scale of distances. If the axis X-X were selected on the line Y-Y in the above construction then the product $F_1'' \times H \times H'$ would give the moment of inertia of force F with respect to axis Y-Y. The product of inertia of all the forces F_1, F_2 and F_3 with respect to axes Y-Y and X-X is of course given by $\Sigma F''\ H\ H'$ or in Fig. 3 by $N \times H \times H'$.

If, as in the above construction, F_1, F_2 and F_3 are considered as parallel forces applied at points P_1, P_2 and P_3, respectively, then these forces have a center of gravity which can be found by the ordinary construction for finding the center of gravity.

In Fig. 3, point R, which is located on the intersection of lines A_1A and DD_1, the closing lines of the equilibrium polygon A_1C_1 D_1 $D\ R$, gives the location of the line parallel to axis Y-Y on which the center of gravity lies. If we now choose another direction X-X, and consider forces F_1, F_2 and F_3 as acting parallel to X-X, finding line GM in a manner similar to the construction for finding RG, then the intersection G of lines GM and RG will give the center of gravity of the forces F_1, F_2 and F_3. In Fig. 3, line GM is found by using force polygon $a'\ d'\ O''$ and equilibrium polygon RMS corresponding to this force polygon.

Let us assume that the distance proportional to the statical moments of forces F_1, F_2 and F_3 about Y-Y, that is F_1', F_2' and F_3' have been found by the construction shown in Fig. 3. If we now consider these statical moments as forces applied at P_1, P_2 and P_3, acting first in the direction Y-Y, and then in another arbitrarily chosen direction X-X, and for these forces F_1', F_2', F_3' we find a center of gravity by the method given above, this center of gravity of the statical moments of F_1, F_2 and F_3 about Y-Y is called the "Center Relative to Y-Y."

7. *Conjugate Diameters.*

(a) Two lines are called conjugate diameters when the relative center of each lies upon the other, when these lines are considered in connection with the same set of forces.

(b) It is proven in Mr. Janni's paper that if a center relative to one axis falls upon a second axis, the center relative to the second will fall upon the first. This will become evident in the construction for the relative centers of two conjugate diameters—as previously outlined.

(c) The center relative to an axis passing through the center of gravity of a system of forces (or elastic weights) lies on the conjugate diameter at an infinite distance from the center of gravity. This is evident from the expression and construction given above for relative center, in which it appears that as the line for which the relative center is being found for a given set of forces, approaches the center of gravity of these forces, the relative center recedes from this center of gravity. The limiting position would then obtain when the line actually passed through the center of gravity of forces and the relative center was located at infinity. That the relative center would be on the conjugate diameter to the line considered is true from (b) above.

(d) The product of inertia of a system of forces (or elastic weights) with respect to two conjugate axes is zero. This is evident from the definitions of relative center and product of inertia, taken in connection with the relation of two conjugate axes as given in (a) above.

It should be noted from (c) that if the center of gravity mentioned is the center of gravity of a system of elastic weights—for example, the center of the ellipse of elasticity of the free end of an arch—the relative center is merely another name for the antipole or center of gravity of statical moments of the elastic weights taken about one of the conjugate lines. This is in line with the remarks concerning antipoles made in Section 5. Thus another way of stating (c) would be: If two conjugate lines pass through the center of gravity of elastic weights, the antipole of each, with respect to the ellipse of elasticity of all the weights, lies at an infinite distance from the center of gravity on the other line. Or (also from the explanation in Section 5) if a force acts along one of the conjugate lines against the center of the ellipse, it will cause a rotation of this center about a point at an infinite distance on the other conjugate line; that is to say, the force will cause no rotation but only a translation at right angles to the line which is conjugate to the line of action of the force.

8. *Product of Inertia and Relative Center of Elastic Weights.*

If in place of ordinary forces we wish to find the product of inertia, moment of inertia, or relative center of elastic weights, the graphical or analytical procedure differs in only one particular. It was stated in Section 5 that the point of application of the moment about any line of an elastic weight is at the antipole, of the line considered, with respect to the ellipse of elasticity of the given elastic weight. From this it follows that, instead of applying the quantities F_1', F_2' and F_3' at points P_1, P_2 and P_3 (Fig. 3) as we did for ordinary

forces in finding the product of inertia with respect to lines Y-Y and X-X, we would proceed as follows:

Suppose P_1, P_2 and P_3 (Fig. 3) to be the centers of the ellipses of elasticity for elastic weights F_1, F_2 and F_3 and that the lengths of axes and their positions for the three ellipses are given. Find the antipoles of line Y-Y with respect to the three ellipses whose centers are P_1, P_2 and P_3, by the method given in Section 5. Then in finding the product of inertia the elastic weights F_1, F_2 and F_3 are applied at P_1, P_2 and P_3 in the direction Y-Y, as in the first construction in Fig. 3, and the intercepts F_1', F_2' and F_3' are found. These

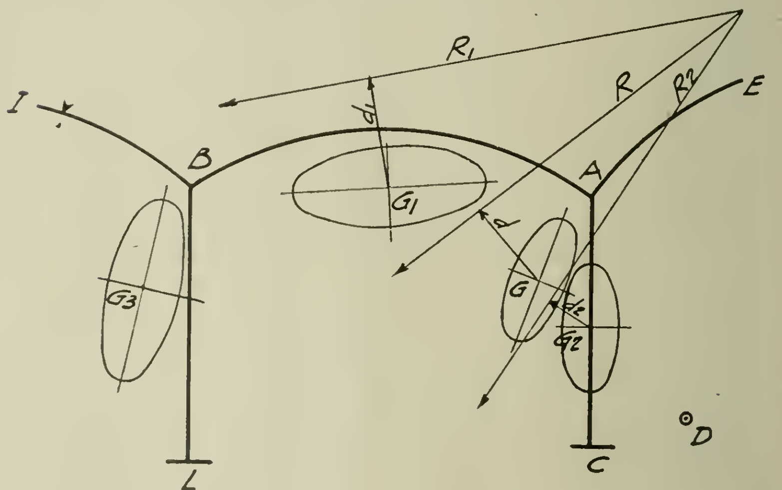

FIG. 6.

intercepts are then applied at the antipoles P_1', P_2' and P_3' in the direction X-X as forces, and, the intercepts F_1''', F_2''' and F_3''' found as before. The product of inertia of the elastic weights with respect to axes Y and X is then (see Fig. 3) given by

$$F_1\, x_1\, y_4 + F_2\, x_2\, y_5 + F_3\, x_3\, y_6 = N' \times H' \times H,$$

in which N' is measured to the scale adopted for the elastic weights and H' and H are measured to the scale of distance.

9. *Construction of Conjugate Diameter.*

To find the position of the conjugate diameter to axis Y-Y (Fig. 1) having given the condition that both Y-Y and the required conjugate line pass through G (the center of gravity of the elastic weights of the subdivisions of the arch rib to be considered), proceed as follows:

Choose a line Y'-Y' parallel to Y-Y, find the statical moments of the given elastic weights about this line, then find the center of gravity of these statical moments when these are applied,

first horizontally then vertically, at the antipoles of the line Y'-Y', with respect to the ellipses of elasticity of the subdivisions of the arch. This construction gives the relative center R of the line Y'-Y'. By joining this relative center with the center of gravity of the elastic weights, G, we have the conjugate diameter to Y'-Y' and also to Y-Y, since these are parallel lines. The only difference as regards the relative center between Y-Y and Y'-Y' is that the relative center R of Y'-Y' (Fig. 1) lies at a finite distance on X-X from G, while the relative center of Y-Y lies at an infinite distance from G on X-X [see Section 7, (c)]. For the process of finding antipoles and the center of gravity of statical moments see Sections 5 and 6.

10. *Semi-Axes of Ellipse of Elasticity of the Free End of an Arch.*

By the use of Sections 5 and 8 we can obtain the moment of inertia of the elastic weights of the arch subdivisions about line Y-Y when the weights are applied as forces parallel to Y-Y. We can also obtain the moment of inertia about X-X of these elastic weights applied as loads parallel to X-X. If we denote the first moment of inertia by Iy and the second by Ix, then from the theory given by Prof. Ritter, the perpendicular distance from Y-Y of the tangent to the ellipse of elasticity of the free end A (Fig. 1) at point L is given by the equation

$$r_1 = \sqrt{\frac{Iy}{\Sigma w}}$$

and the perpendicular distance from X-X of the tangent at L' by the equation

$$r_2 = \sqrt{\frac{Ix}{\Sigma w}}$$

in which Σw denotes the sum of all the elastic weights of the subdivisions of the arch.

11. In Part II of this paper it is shown that the solution of the unsymmetrical elastic arch by the method of the ellipse of elasticity depends upon (1) the expressions for the deflection of the free end A (Fig. 1) in the direction of lines X-X and Y-Y, the two conjugate diameters of the ellipse of elasticity of the arch, and (2) upon the angle of rotation of the free end A.

It will now be shown that the expressions for deflection involving the use of the ellipse of elasticity are identical with the ordinary formulæ for deflection used in the elastic theory of structures.

Referring to Fig. 11, the deflection due to a load P of the free end B of the cantilever AB, along line BX is

$$\triangle x = \int_0^a \frac{Myds}{EI} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

For proof of (7) see Johnson, Bryan and Turneaure, "Statically Indeterminate Structures," Part II, or Church's "Mechanics."

In equation (7) M is the moment at any section of the beam, y is the vertical distance of this section above point B, ds is the length of the element of AB over which moment M is constant, E is the modulus of elasticity of the material, and I is the moment of inertia of the cross section of the beam.

Substituting in (7) for M in terms of P and integrating between the limits $y = o$ and $y = a$

$$\triangle x = \frac{Pabl}{3EI} \qquad (8)$$

Now the theory of the ellipse of elasticity states that the deflection $\triangle x$ is equal to the product of inertia of the elastic weight of the cantilever AB, with respect to the lines PB and BX, multiplied by the force P. That is

$$\triangle x = \frac{l}{EI} \, . \, P \, . \, \frac{b}{2} \, . \, Y \qquad (9)$$

In which $\frac{l}{EI} = \Sigma \frac{ds}{EI}$, or the elastic weight of the cantilever, and Y is the distance from line BX to O, the antipole of line PB with respect to the ellipse of AB.

For the case under consideration, we will assume constant moment of inertia of the beam. The center of the ellipse of the beam falls at the center of gravity of the beam in this case (see Part II).

Note that from previous sections, the radii of the ellipse are

$$r_1 = \sqrt{\frac{I}{A}} \qquad (10)$$

$$r_2 = \sqrt{\frac{l}{12}} \qquad (11)$$

and that the location of antipole O is given by

$$d_1 - \frac{2aI}{blA} \qquad (12)$$

and

$$d_2 = \frac{l}{6} \qquad (13)$$

and therefore

$$Y = \frac{2a}{3} - \frac{2aI}{Al^2} \qquad (14)$$

Substituting in (9) from (10), (11), (12), (13) and (14), we obtain

$$x = \frac{Pabl}{3EI} - \frac{Pab}{AEl} \quad \text{.......................} (15)$$

It will be seen that in (15) the expression for deflection does not agree with that given in (8) which results from the ordinary theory for deflection due to moment only.

The elongation of AB, due to direct stress, that is, due to the component of P along AB, is by the ordinary elastic theory for distortion due to direct stress.

$$\triangle_1 x = \frac{Sl}{AE} = \frac{Pla}{lAE} \quad \text{.......................} (16)$$

The component of this elongation along line BX is

$$\triangle_2 x = \frac{Pla}{lAE} \cdot \frac{b}{l} = \frac{Pab}{AEl} \quad \text{.......................} (17)$$

This is identical with the second term of the expression for deflection along BX, given in (15) above. This shows, then, that while (8) gives only the deflection due to moment, the ellipse of elasticity method gives at once, both the deflection due to moment and that due to direct stress.

In a similar manner to the above it can be shown that by the method of the ellipse we take into account also the deflections along line PB both due to moment and direct stress.

Referring again to figure 11, the ordinary elastic theory states (see Johnson, Bryan and Turneaure) that the angular motion of point B due to load P is given by

$$d\phi = \int_0^l \frac{Mds}{EI} \quad \text{.......................} (18)$$

In which, as before, M is the moment in the beam at any section and ds is the elementary length over which M is constant.

Substituting for M in terms of P and s, where s is the distance along AB, from B to the point where any moment is taken, then

$$d\phi = \int_0^l \frac{Pbsds}{EI}$$

$$= \frac{Pbl}{2EI} \text{ (integrating) } \quad \text{..................} (19)$$

Now, the theory of the ellipse states that the angular motion due to P is equal to the elastic weight of the beam multiplied by the distance from the center of gravity of this elastic weight to the line of action of P, multiplied by the force P. As before, the

elastic weight of the beam is $\Sigma \dfrac{ds}{EI} = \dfrac{l}{EI}$, assuming constant moment of inertia. The center of gravity of this elastic weight is at G (Fig. 11). Therefore

$$d\phi = \frac{l}{EI} \cdot \frac{b}{2} \cdot P = \frac{Pbl}{2EI} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

The above expression is identical with that given in (19).

Thus we have shown that the formulæ for deflection which we shall use in Part II in the solution of the unsymmetrical arch are identical with the ordinary formulæ of the elastic theory, and take account of deflections due to bending and direct stress, and also take into account angular motion.

Note that as stated in Section 5, the expression in (9) for deflection is such that the moment of the elastic weight about line PB may be considered applied at the antipole O and to have a lever arm Y about line BX. The product of this moment of the elastic weight by PY gives the desired deflection.

PART II.

APPLICATION OF THEORY TO A SINGLE UNSYMMETRICAL ARCH SPAN.

The necessary steps for solving the single unsymmetrical arch will not be outlined. The explanation of the results obtained will be given after the outline. An understanding of the explanation will depend largely on the reader's keeping in mind and referring to the formulæ and general relations given in Part I.

Example.—Given the unsymmetrical reinforced concrete arch rib shown in Fig. 4, the sections and reinforcement of which have been selected by some empirical method, or by reference to other structures. The first step is to divide the arch axis into an arbitrary number of lengths, which lengths are preferably, but not necessarily, equal, and small enough so that the moment of inertia of the cross section of any subdivision may be considered constant.

In calculating these moments of inertia, account should be taken of the reinforcement in the rib. That is, the area of steel should be considered increased n-fold, where n is the ratio of the modulus of elasticity of steel to that of concrete.

Now, calculate the value of the modified elastic weight $\dfrac{ds}{I}$ for each of the elements *1, 2, 3 .... 14*. It is not necessary to calculate the value $\dfrac{ds}{EI} = w$, as the E cancels out in the later operations except for the case of temperature stresses, where it must be taken into account. The "E" here mentioned is the modulus of elasticity of concrete.

Next calculate the radii of the ellipses of elasticity of the elements *1, 2, 3* .... *14*. The radius $r_1 = \sqrt{\frac{I}{A}}$ for each element, and $r_2 = ds\sqrt{\frac{1}{12}}$, as explained in Part I. It will be noted that for subdivisions of equal length the radii r_2 are all equal.

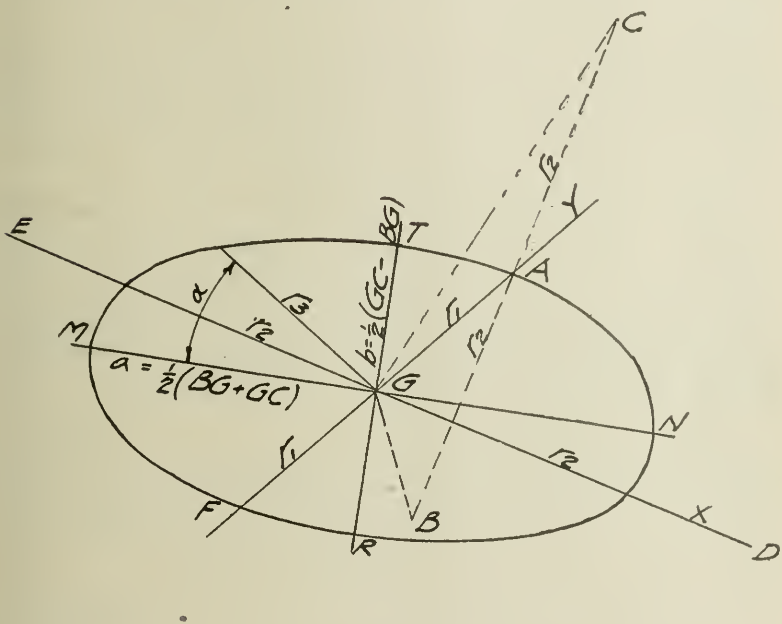

FIG. 7.

Polygon p_1: At the left of the drawing select an arbitrary vertical as a load line and plot the elastic weights on it as loads (see Fig. 4). With the pole distance $H_1 = \Sigma w$ draw the force polygon $A_1B_1O_1$. Dropping verticals from points *1, 2, 3* .... *14*, draw the equilibrium polygon p_1, whose sides connect these verticals and are parallel to corresponding rays in the force polygon $A_1B_1O_1$. By this construction we have applied the elastic weights as vertical loads at the points *1, 2, 3* .... *14*. The intersection C_1 of the closing lines of polygon p_1 gives the vertical on which lies the center of gravity of the elastic weights, *1, 2, 3* .... *14*, *i. e.*, the line *Y-Y*. It will be noted that the sides of polygon p_1 cut off on *Y-Y* the segments w_1'', w_2'' .... w_{14}'', which are proportional to the moments about *Y-Y* of the different elastic weights.

Polygon p_2: The intersection of the closing lines of polygon p_1 gives the vertical line Y-Y on which lies the center of gravity of the elastic weights. If we now use the same force polygon $A_1B_1O_1$, and from it construct the equlibrium polygon p_2', starting from the arbitrary vertical Y'-Y', we will get the horizontal line G-G' on which lies the center of gravity G of the elastic weights. *Polygon p_2'* must be drawn having its sides at right angles to the rays of the force polygon $A_1B_1O_1$, and furthermore, these sides must be so drawn as to intersect the horizontals through the centers of the ellipses of elasticity of the arch elements, i. e., through the centers of gravity of the arch elements. In other words p_2' is the equilibrium polygon for the elastic weights applied as horizontal forces at the centers of the ellipses. Force polygon $A_1B_1O_1$ in combination with equilibrium polygons p_1 and p_2' is therefore nothing more than the necessary familiar construction for finding the center of gravity G of the elastic weights, which was outlined in Section 6.

Now having the gravity point G, and again considering the arbitrary vertical Y'-Y', let us find the conjugate diameter to this vertical by the method explained in Sections 8 and 9, i. e., find the relative center C of Y'-Y' and connect C with G, giving X-X, the conjugate diameter to Y-Y and also to Y'-Y', which conjugate diameter passes through the center of gravity G. This construction is not shown in Fig. 4, it having been sufficiently outlined in Sections 8 and 9 of Part I.

Now apply the elastic weights *1, 2, 3....14* at the centers of the ellipses as loads in a direction parallel to X-X. For this purpose use force polygon $A_2O_2B_2$, with the arbitrary pole distance H_2, whose load line $A_2B_2 = \Sigma w$ and is parallel to X-X. Corresponding to this force polygon draw equilibrium polygon p_2 whose sides are parallel to the rays of $A_2O_2B_2$, and connect lines parallel to X-X through the centers of the ellipses *1, 2 .... 14*. Note that the sides of p_2 produced, cut off on X-X segments w_1', $w_2' \ldots w_{14}'$, proportional to the moments about X-X of the elastic weights *1, 2, 3....14*. The closing lines of polygon p_2 should intersect in point G, giving a check on the previous construction for this point.

Polygon p_3: By the method explained in Section 5, construct the antipoles v_1, v_2, $v_3 \ldots v_{14}$ of the vertical Y-Y with respect to the ellipses *1, 2, 3....14*. Considering the segments w_1'', w_2'', w_3'' $\ldots w_{14}''$ as vertical loads, apply them at these antipoles. For this purpose use force polygon $A_3O_3C_1$, and corresponding to it equilibrium polygon p_3 whose closing lines C_3 are parallel.

Polygon p_4: In a similar manner to the above find the antipoles h_1, $h_2 \ldots h_{14}$ of line X-X with respect to the ellipses *1, 2, 3 .... 14*. Then use the segments w_1', w_2', $w_3' \ldots w_{14}'$ as loads at these antipoles applied in a direction parallel to X-X. To make this construction use force polygon $A_4O_4B_4$ with a pole distance equal to N_3, the distance between the last sides C_3 of polygon p_3. Corresponding to force polygon $A_4O_4B_4$ draw equilibrium polygon p_4, whose sides are

parallel to the rays of $A_4O_4B_4$ and connect lines parallel to X-X, through the antipoles $h_1, h_2, h_3 \ldots h_{14}$.

Polygon p_5: Again using the segments $w_1', w_2', w_3' \ldots w_{14}'$ as loads at the antipoles $h_1, h_2, h_3 \ldots h_{14}$, this time as vertical loads, construct the force polygon $A_5O_5B_5$, with the pole distance N_4 equal to the distance between the outside lines of the polygon p_4, measured parallel to X-X. Corresponding to $A_5O_5B_5$ draw the equilibrium polygon p_5 connecting the verticals through antipoles $h_1, h_2 \ldots h_{14}$.

From polygon p_3 we can now obtain the vertical components of the two end reactions of the arch. Calling the distance N_3 between the two closing lines equal to unity, then for a load unity at the vertical P on the arch, the vertical component of the left reaction is (to the scale $N_3 = 1$) equal to the distance V_1. Correspondingly, V_2 is the vertical component of the right reaction, to the scale $N_3 = 1$.

In polygon p_5 the ordinate H is (to the same scale mentioned above) equal to the component of either reaction in the direction X-X.

In polygon p_1 the ordinate M_1 is to the scale of distances used in the drawing equal to the moment of the left reaction R_1 about the center G for a load unity at P.

To construct R_1 and R_2 the two reactions, to scale, draw H to scale at the position shown in polygon p_3; then connect the ends of V_1, V_2 and H by the lines R_1 and R_2, which will then be the values of the two reactions for a load unity on the vertical P, to the scale $N_3 = 1$.

To find the true position of R_1, note that the moment of R_1 about G equals M_1. Therefore, the perpendicular distance from G to the true line of action of R_1 is

$$d_1 = \frac{M_1}{R_1}$$

In like manner

$$d_2 = \frac{M_2}{R_2}$$

The three polygons p_1, p_3 and p_5, therefore, give us a means for finding the values and the true positions of the thrusts on the arch due to a vertical load of unity in any position on the arch. Having the values of the thrusts for a load unity we can, of course, find their values for any load at the same point by simply multiplying the thrust for the unit load by the amount of the given load. The lines of action of the thrusts R_1 and R_2 will, of course, be the same for any load as for the unit load at the same position.

To find the maximum thrust, shear, and positive or negative moment on any section as A-A, of the arch rib, it will be necessary to draw in the thrust lines corresponding to R_1 and R_2 for every position which the live load might take. The moment on the section A-A for a load at P for example, is then equal to R_1x. The shear

on the section is the value of the component of R_1 which is at right angles to the arch axis at *A-A*. The normal thrust on section *A-A* due to a load at *P* is the component of R_1 which is parallel to the tangent to the arch ring axis at *A-A*. We can, therefore, draw influence lines for thrust, shear and bending moment on section *A-A* due to a live load at any point.

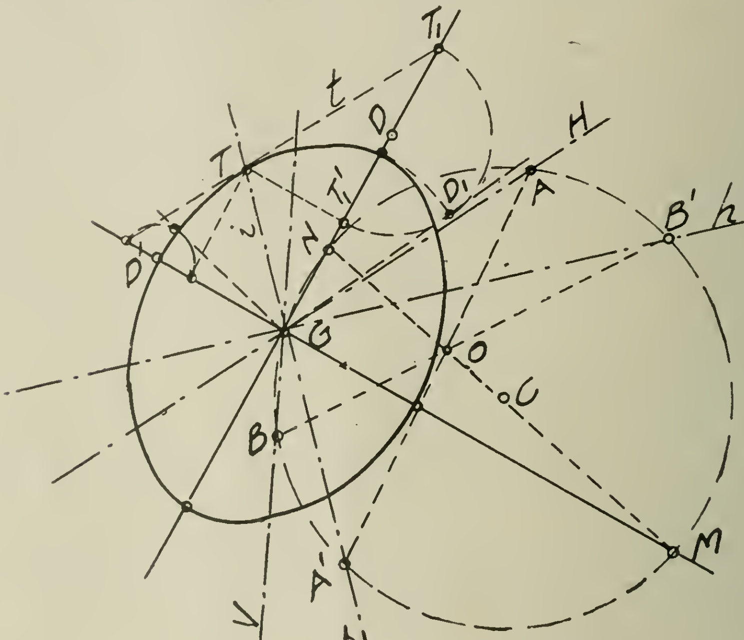

FIG. 8

To illustrate the work of constructing influence lines, Fig. 10 has been drawn. Assuming loads P_3, P_4, P_5 and P_6 to indicate the four possible positions on the arch, of a live load concentration, we find, from polygons p_1, p_3, and p_5 (which are the influence lines for reactions due to a load of unity in any position), the corresponding reactions R_3, R_4, R_5 and R_6 which affect section *A-A* of the arch rib. These reactions are found in amount and location in the manner above described.

Next, taking *MN* as the zero axis, we plot $R_3 \times d_3$, the moment at section *A-A*, due to a load of unity at P_3, in the position shown. The thrust R_3 will cause tension in the upper flange of the arch rib, as is indicated by its location relative to arch axis at section *A-A*. In like manner we plot—R_4d_4, —R_5d_5, and $+R_6d_6$, in the influence diagram for moments, under their corresponding loads. It will be noted by referring to the figure that the moment R_6d_6, due to a load unity at P_6, is positive, as the reaction thrust R_6 passes on the upper side of the arch axis at section *A-A*, thus producing compression in

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Morell—Ellipse of Elasticity.

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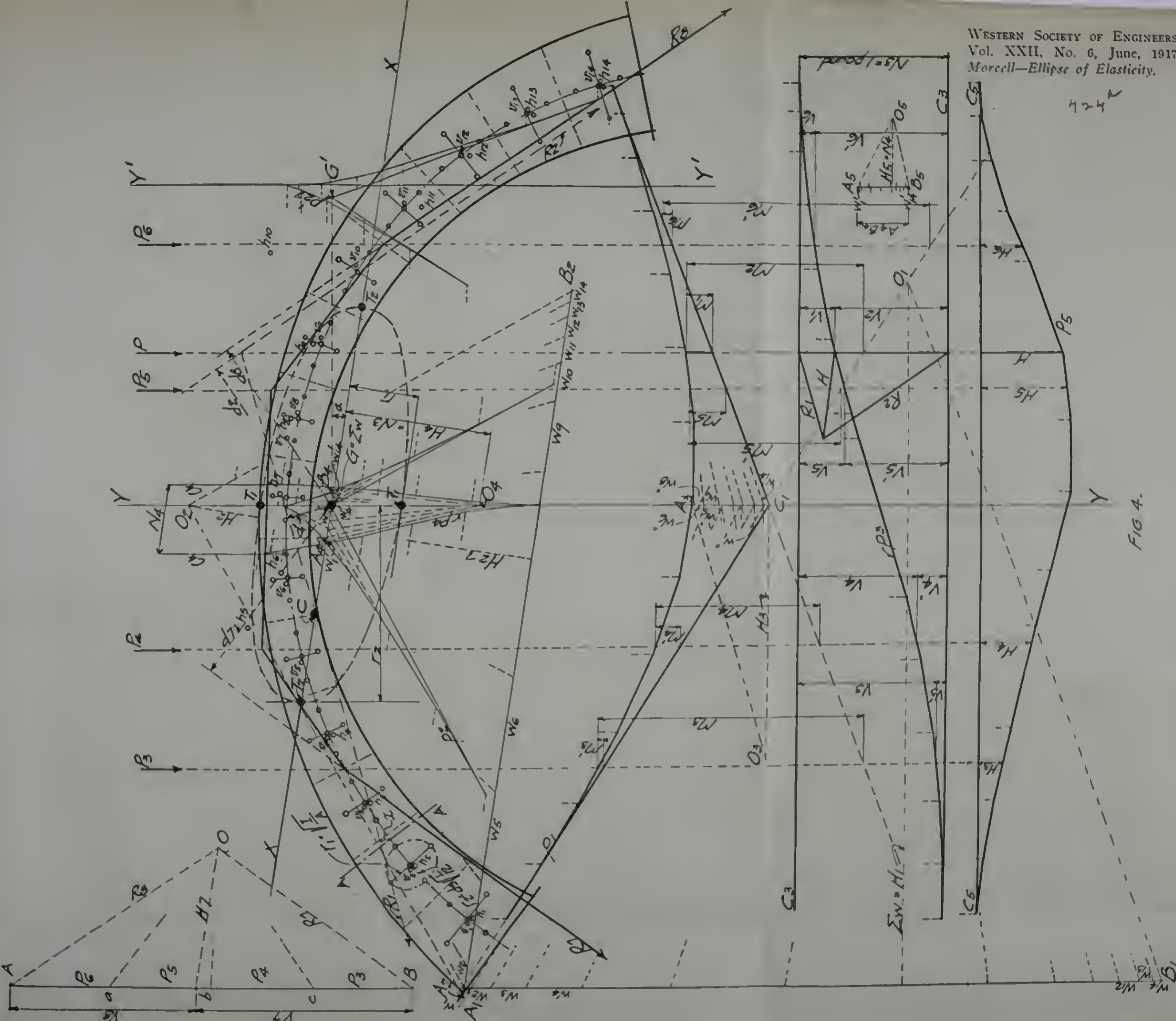

FIG 4.

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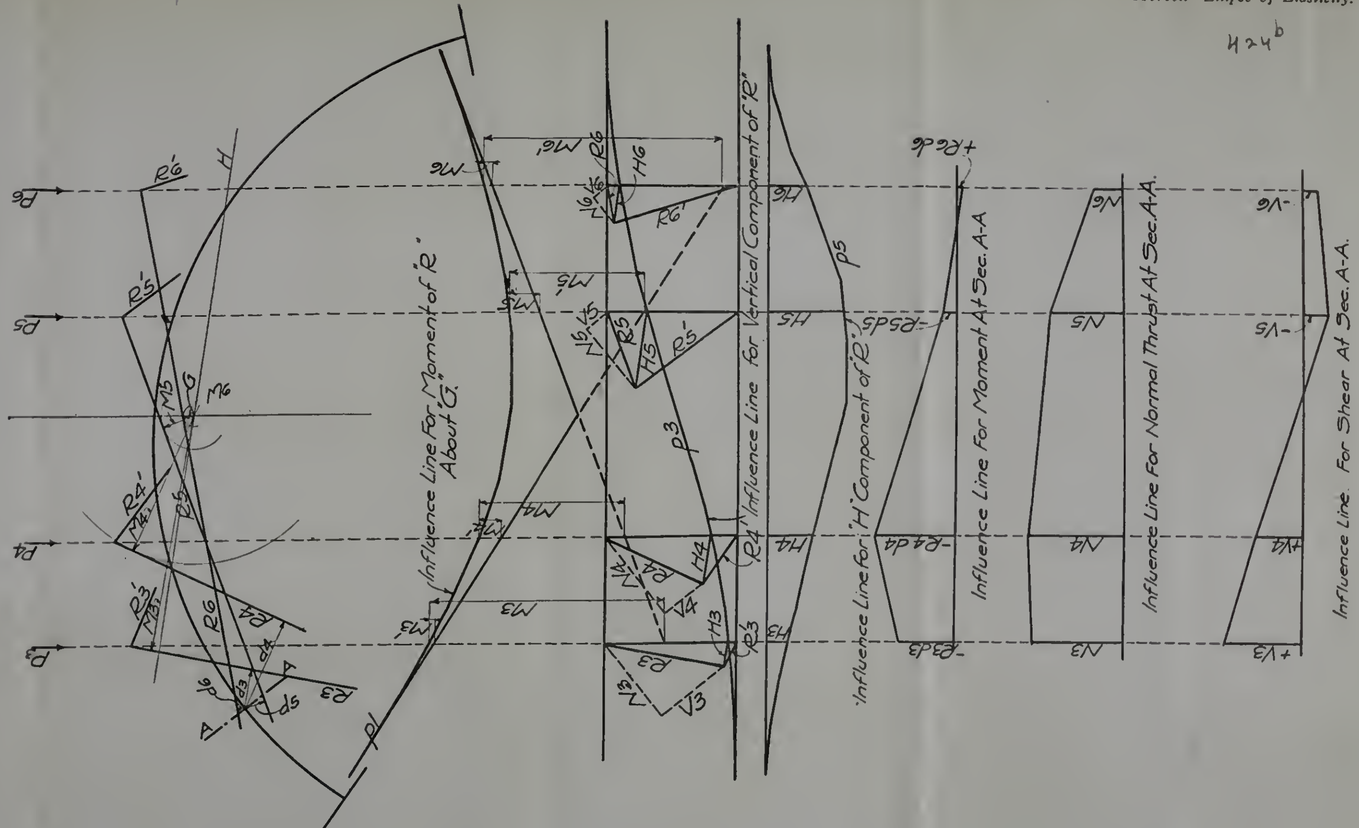
Influence Line For Moment of "R" About "G".
Influence Line for Vertical Component of "R"
Influence Line for "H" Component of "R"
Influence Line For Moment At Sec. A-A
Influence Line For Normal Thrust At Sec. A-A.
Influence Line For Shear At Sec. A-A.

FIG. 10.

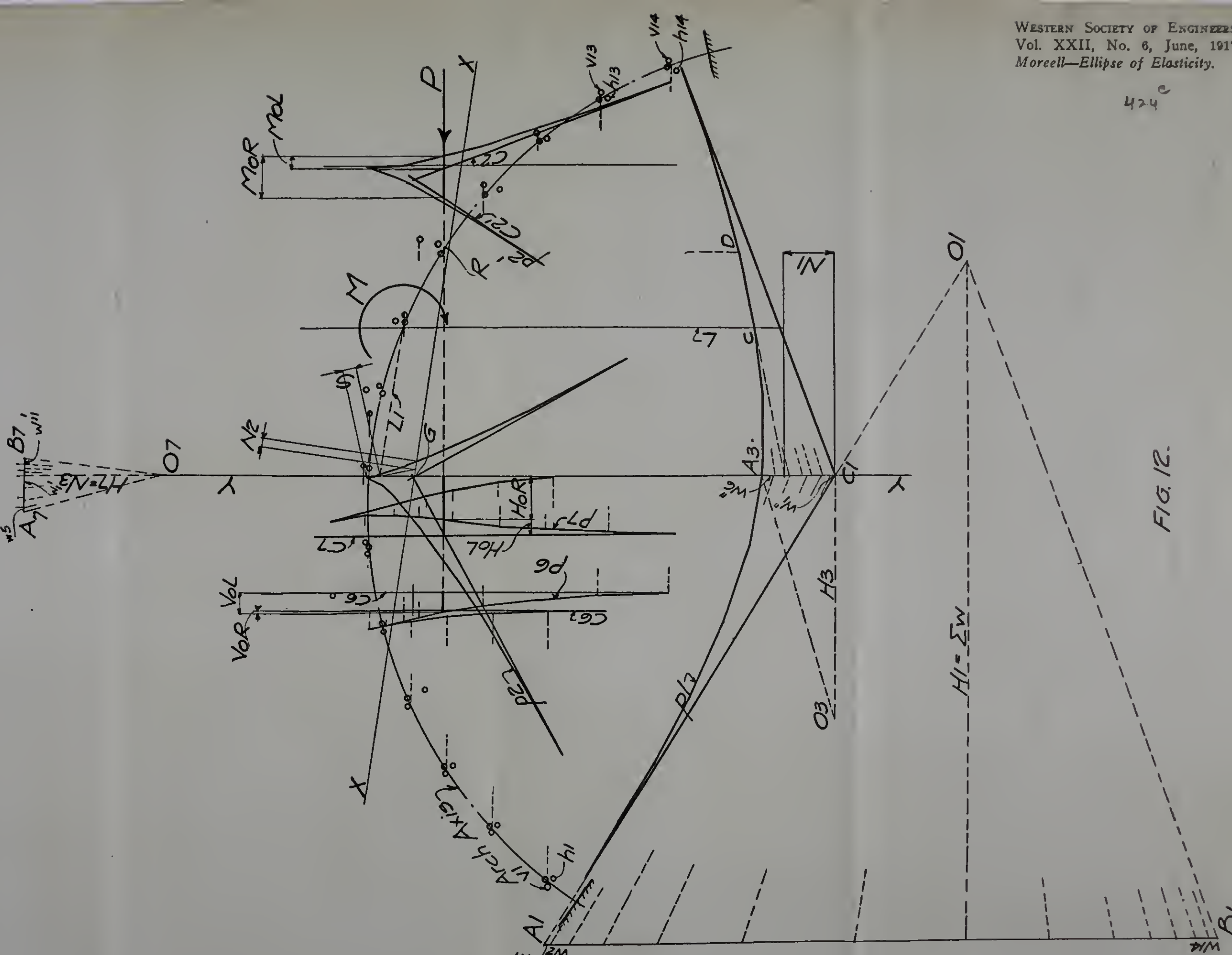
P
X
Y
MoR
MoL
M
R
G
O7
B7
A7
H7=N3
O1
O3
C1
A1
B1
H3
H1=ΣW
Arch Axis
HoR
HoL
VoL
VoR
p6
p7
p13
p22
p27
L7
D
IN
A3
V14
h14
V13
h13
V1
h1

FIG. 12.

the upper fibres and tension in the lower fibres of the arch rib. By multiplying the moment ordinates $-R_3d_3$, $-R_4d_4$, $-R_5d_5$, by the maximum live load concentrations which are possible at their respective load points, P_3, P_4 and P_5, and summing up the resulting moments, we can obtain the maximum possible negative live load moment for section *A-A*. Similarly, we can find the maximum negative live load moment at section *A-A*, by loading P_6 with its greatest live load concentration. Similar constructions may be made for any other special sections of the arch rib, for which maximum moments are desired.

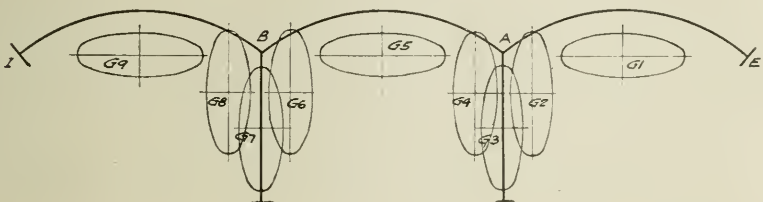

FIG 9.

The influence line for normal thrust on section *A-A* (see Fig. 10) is obtained by plotting on a base line *OP*, the components of R_3, R_4, R_5 and R_6, which are tangential to the arch axis at section *A-A*. This gives the normal thrust on *A-A* due to a load unity at points, P_3, P_4, P_5 and P_6. Multiplying these thrusts by the maximum possible live loads at their respective points of loading, and summing up, we obtain the maximum live load thrust on section *A-A*.

The influence line for shear on section *A-A* is drawn by plotting vertically on line *RS*, the components of thrust R_3, R_4, R_5 and R_6, which are at right angles to the arch axis at section *A-A*. Care must be taken in order to plot properly the direction of this component, as this is what determines the change in sign of the shear. Thus, it will be seen that if we consider the shear components of R_3 and R_4 to pass downward relative to section *A-A*, those of R_5 and R_6 pass in opposite direction. Therefore, to get the maximum shear of one sign we load points P_3 and P_4, while to get the maximum of the opposite sign, we load points P_5 and P_6.

It will be noted that for a single symmetrical arch span the work of obtaining the influence lines for reaction is very much reduced and simplified. In such a case it is necessary to draw only portions of polygons p_1 to p_5 on one side of the line *Y-Y*, as the right halves of these figures are a repetition of the left. Also the construction for the conjugate diameter need not be made, as for a symmetrical arch the conjugate to line *Y-Y* is the horizontal through *G*.

DEAD LOAD.

The line of thrust for the dead load on the span should be drawn first, i. e., before the live load thrusts are found, so that (especially in highway structures) preliminary fiber stresses may

be found for dead load. In this way it can be determined whether or not it is advisable to go on with the live load calculations for the section of rib selected, or whether it is preferable to choose another section. The method here given for dead load (which is that of Prof. Ritter), involves no additional mathematical theory.

Suppose (Fig. 4) that P_3, P_4, P_5 and P_6 are the dead load concentrations on the span. To find, for example, the left reaction R_7 due to all these loads, find the sum of $P_3V_3 + P_4V_4 + P_5V_5 + P_6V_6$. This sum will give the vertical component V_7 of the left reaction R_7 due to dead load. In the same manner the sum of $P_3H_3 + P_4H_4 + P_5H_5 + P_6H_6$ will give the component H_7 of R_7 in the direction X-X. It is now an easy matter to construct the value of R_7 by laying off V_7 vertically and H_7 parallel to X-X, and connecting the extremities BO by the line R_7 (see Fig. 4). To find the location of R_7 with respect to the center G note that the sum of the moments of the reactions R_3, R_4, R_5 and R_6, about G, due to the single loads P_3, P_4, P_5 and P_6 respectively is equal to the moment of the total reaction R_7 about G. To find the distance d_7 of R_7 from G, solve the relation:

$$R_7d_7 = P_3M_3 + P_4M_4 + P_5M_5 + P_6M_6$$

for d_7, since R_7 is now known and $M_1 \ldots . M_6$ can be scaled from polygon p_1.

In a similar manner the right reaction R_8 can be obtained in amount, direction and location. For this purpose use ordinates $M_3' \ldots . M_6'$ and $V_3' \ldots . V_6'$

Let us now construct the force polygon AOB with the given loads P_3, P_4, P_5 and P_6 and the reactions R_7 and R_8, and draw the rays aO, bO, cO. Then, commencing at the point where the line of action of R_7 cuts the vertical P_3, draw the true dead load pressure line, making the sides parallel to the respective rays of the force polygon AOB. The last side, which is parallel to the ray aO, should end in the point of intersection of R_8 and the load line P_6, since R_8 has already been located.

EXPLANATION OF RESULTS OBTAINED

Before going into the stresses due to temperature a rational explanation of the results obtained above is in order. This will be made with the aid of the relations demonstrated in Part I, Section 11.

In the development of the arch theory the span (Fig. 4) is assumed fixed at the right end and free at the left end. This means, as heretofore explained, that the arch offers a cantilever support for any applied load P, or a like support for the required reaction R_1, developed by P. In this manner the arch structure is replaced by a statically determinate support. The deflection of the left end due to P is then expressed, and this expression for deflection equated to the expression for the deflection in an opposite direction due to R_1. These two deflections must be equal, as the left end, being fixed, in reality goes through no deflection

It was found convenient to express the total motion of point *G*, due to any external load on the cantilever, as the resultant of three component motions (see Part I, Section 11):

(1) A motion along line *Y-Y* without rotation.

(2) A motion along line *X-X* without rotation.

(3) A rotation.

It has been proved (Part I, Section 11) that the displacement along any line *Y-Y* due to an external load *P* is equal to the product of inertia of the elastic weights to the right of *P* with respect to the line of action *P* and the direction of displacement *Y-Y*. Now by referring to Section 6, Part I, we note that the ordinate V_1 in polygon p_3 is proportional to this product of inertia, which is equal to the product of V_1 and the two pole distances H_1 and H_3, i. e., the total displacement along *Y-Y* is,

$$\Delta y = P \,.\, V_1 \,.\, H_1 \,.\, H_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

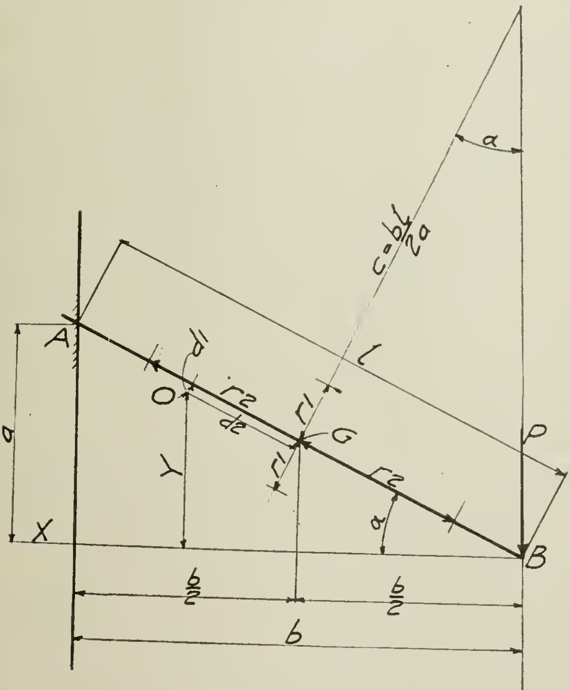

FIG. 11.

In like manner the displacement of *G* along *X-X* is equal to the product of the force *P* and the product of inertia of the elastic weights to the right of *P* (as these elastic weights only and not those to the left are affected by the action of *P* on the cantilever) with respect to the line of action of *P* and the line *X-X* along which the

displacement takes place. As before, referring to Section 6, Part I, this product of inertia is proportional to the ordinate H in polygon p_5, and equal to the product of H and the two pole disances H_5 ($=N_4$) and H_2, or,

$$\triangle x = P \cdot H \cdot N_4 \cdot H_2 \qquad (2)$$

It was also proved that the angular displacement or rotation of G, due to a load P, is equal to the load P multiplied by the statical moments of all the elastic weights to the right of P, about the line of action of P. By the construction of polygon p_1, the ordinate M_1 was made proportional to this statical moment, which is equal to the product of M_1 and the pole distance H_1, that is, the angular displacement is,

$$\delta = PM_1H_1 \qquad (3)$$

In order to bring back the point G (or the free end of the arch) to its location before being displaced by P we must have a reaction V_0 along Y-Y to reduce $\triangle y$ to zero, a reaction H_0 along X-X to reduce $\triangle x$ to zero, and a reaction moment M_0 about point G to reduce the angular displacement δ to zero.

Considering V_0 as an external load applied at G, in the direction Y-Y, the displacement due to V_0 will be similar to that for P and equal to the product of inertia of all the elastic weights of the arch with respect to the line of action of the force and the line of displacement, which in the case of V_0 are identical lines. As explained in Section 6, Part I, this product of inertia reduces in this case to the moment of inertia about line Y-Y, the line of action of V_0. The reason for using all the elastic weights to get the displacement due to the reaction V_0, evidently is that all the elastic ellipses are relatively displaced by the action of a reaction on the left end of the arch, while in the case of a load P on the cantilever with the left end free, only the elastic ellipses to the right of P are displaced relative to each other.

Now by the construction of polygon p_3 the distance N_3 between the outside lines is proportional to the moment of inertia of all the elastic weights about line Y-Y, and the actual value of this moment of inertia will be N_3 multiplied by the product of the pole distances H_1 and H_3. Therefore the displacement due to V_0 is

$$\triangle y = V_0N_3H_1H_3 \qquad (4)$$

In like manner the displacement due to the reaction H_0 along X-X is equal to H_0 multiplied by the moment of inertia of all the elastic weights about the line X-X, which moment of inertia is equal to the extreme ordinate N_4 of polygon p_4 multiplied by the pole distances H_4 ($=N_3$) and H_2, that is

$$\triangle x = H_0N_4H_2N_3 \qquad (5)$$

It was also proved that the angular displacement due to the reaction moment M_0 is equal to the product of M_0 by the sum of all the elastic weights (Σw). Therefore

$$\delta = M_0\Sigma w \qquad (6)$$

Let us now equate the two sets of expressions for the three displacements obtained above.

From (1) and (4)

$$P_1V_1H_1H_3 = V_0N_3H_1H_3 \quad \text{(7)}$$

From (2) and (5)

$$PHN_4H_2 = H_0N_4H_2N_3 \quad \text{(8)}$$

From (3) and (6)

$$PM_1H_1 = M_0\Sigma w \quad \text{(9)}$$

Remembering that in equation (7) N_3 is equal to unity in the scale of forces, then

$$V_0 = PV_1 \quad \text{(10)}$$

Likewise from (8)

$$H_0 = PH \quad \text{(11)}$$

And from (9), since H_1 was made equal to Σw.

$$M_0 = PM_1 \quad \text{(12)}$$

Equations (10), (11) and (12) show that the components of reaction R_1 can be scaled from polygons p_3 and p_5, and the position of R_1 relative to point G can be obtained by the use of moment M_1 scaled from polygon p_1.

To make it clear why the curves in Fig. 4 were drawn using the two axes Y-Y and X-X, which are conjugate diameters of the ellipse of elasticity of the free end of the arch, refer to Section 7, Part I, where we have the statement that a force acting along one of two conjugate lines passing through the center G will cause a rotation about the antipole of this line, which antipole lies on the conjugate diameter at infinity. This means that the reaction H_0 in equation (11) will cause point G to rotate about a point infinitely distant from G on line Y-Y, which rotation is evidently equivalent to a translation of G at right angles to Y-Y. In like manner, the reaction V_0 will produce a translation of point G at right angles to line X-X, the conjugate line to the direction of V_0. In other words, the displacement due to V_0 has no component along X-X, therefore not altering the value of H_0; and the displacement due to H_0 has no component along Y-Y, therefore not altering the value of V_0. These considerations make equation (4) the complete expression for the vertical displacement due to V_0, and equation (5) the complete expression for the component along X-X, of the displacement due to H_0.

EFFECT OF TEMPERATURE.

Considering still that the left end of the arch is free, the displacement of this end due to a rise or fall in temperature of $t°$ will be,

$$\Delta c = Lct° \quad \text{(13)}$$

in which L is the chord length of the arch, and c is the coefficient of expansion due to temperature. This expansion or contraction

due to temperature being a displacement along a straight line (*i. e.*, the chord of the span), may be regarded as a rotation about an infinitely distant antipole. Since there is no rotation of the free end and therefore none for point G, which is assumed in rigid connection with this end, the reaction thrust due to this tendency toward lengthening of the arch chord must pass through G. Moreover, a motion of the free end along the chord of the arch, and therefore a motion of point G parallel to this chord, would mean a rotation of this free end or the point G about a point (antipole) infinitely distant from the chord and lying on a line perpendicular to the chord. Now since the reaction thrust passes through G and the center of rotation due to this thrust lies on a perpendicular to the arch chord, also passing through G, this thrust line and this perpendicular must be conjugate diameters; for by the definition of conjugate diameters, the center of rotation for one lies on the other. Therefore, to find the direction of the temperature thrust, it is necessary to find the conjugate diameter to the perpendicular to the arch chord, which perpendicular passes through G, as also does the conjugate diameter. Usually the arch chord is a horizontal line so that the conjugate diameter to be found is the conjugate X-X to line Y-Y (Fig. 4), which is taken vertical. Should the arch chord be inclined to the horizontal, it would be necessary to find another conjugate line.

Let T be the thrust passing through G, due to temperature, and suppose that it acts along the axis X-X, *i. e.*, the chord of the arch is horizontal. Then the motion of G due to T will be along line X-X, and be equal to the moment of inertia of all the elastic weights about line X-X multiplied by T, as shown above in the case of the reaction H_0, that is,

$$\triangle c = \frac{TN_4H_4H_2}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

in which N_4 is measured to the scale of elastic weights used in lines A_1B_1 and A_2B_2, and H_4 and H_2 to the scale of lengths used in the drawing. The notation E in equation (14) for the modulus of elasticity of the material must be introduced here as it does not cancel out when the displacements represented by equations (13) and (14) are equated.

Equating the expressions for $\triangle c$ given in equations (13) and (14), and solving for T, we have

$$T = \frac{Lct^\circ E}{N_4H_4H_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

which gives the value of the reaction due to temperature. Note, as mentioned above, that this reaction passes through G and lies in the line X-X for the case assumed above (horizontal arch chord). For the case of an inclined arch chord, as mentioned previously, the conjugate diameter to the perpendicular passing through G to this arch chord would have to be found. Also the moment of inertia of all

the elastic weights corresponding to $N_4H_4H_2$ above would have to be used in equation (15). The temperature thrust would then lie in this conjugate line.

By Sections 5, 8 and 10 of Part I, the radius r_1 of the ellipse of elasticity of the free end (Fig. 4) is

$$r_1 = \sqrt{\frac{Ix}{\Sigma w}} = \sqrt{\frac{N_4H_4H_2}{\Sigma w}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

and

$$r_2 = \sqrt{\frac{Iy}{\Sigma w}} = \sqrt{\frac{N_3H_3H_1}{\Sigma w}} = \sqrt{N_3H_3} \quad \ldots\ldots\ldots\ldots (17)$$

Note that in equation (17) H_1 was taken equal to Σw (see force polygon $A_1B_1O_1$). It is evident that the expression $r_1^2 \Sigma w$ could be used for $N_4H_4H_2$ in equation (15), if r_1 has been previously calculated.

In most methods for the reinforced concrete arch, the effect of arch shortening from thrust is usually provided for by the assumption of a uniform unit pressure throughout the rib and then treated as a corresponding fall in temperature. In the present method, this approximation need not be made since the diagrams have taken account of deflections due to thrust. (See Part I, Section 11.)

HORIZONTAL LOADS.

The influence lines for reactions in Fig. 4 suffice for the effect of vertical loads on the arch rib. For horizontal loads two additional equilibrium polygons are necessary.

Polygon p_6 (Fig. 12) is drawn by applying the intercepts w_1'', $w_2''\ldots\ldots\ldots w_{14}''$ of the polygon p_1, horizontally at the antipoles v_1, $v_2\ldots\ldots\ldots v_{14}$ of line Y-Y with respect to the ellipses of elasticity of the arch sub-divisions. For this purpose force polygon $A_3O_3C_1$ is used, and the sides of p_6 are drawn at right angles to the rays of this force polygon.

Then, for a load P, for example, at point R on the arch rib, the vertical deflection of point G is,

$$\Delta y = P \,.\, V_0L \,.\, H_3 \,.\, \Sigma w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

in which Σw is the pole distance of force polygon $A_1O_1B_1$ (Fig. 4).

Equation (18) is correct, since the quantity on the right side is (by reasoning used in former proofs) the product of inertia of the elastic weights between load P and the right end of the arch, with respect to lines P and Y-Y, multiplied by the load P.

Due to the vertical component V, of the left reaction due to P, the deflection is,

$$\Delta y = V \,.\, N_3 \,.\, H_3 \Sigma w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Since the right side of equation (19) is the moment of inertia about the line of action of V of all the elastic weights multiplied by

the force V. The quantity N_3 in equation (19) is taken from polygon p_3 (Fig. 4).

Equating the two expressions for $\triangle y$ (as in previous proofs), cancelling out like terms, assuming P is a load of one pound, and using the scale $N_3 =$ one pound,

$$\therefore V = V_0L \ldots\ldots (20)$$

which gives the value of the vertical component of the left reaction due to a horizontal load of one pound at R. In like manner V_0R is the vertical component of the right reaction.

Let us now draw equilibrium polygon p_7, by applying as loads at the antipoles of line X-X, the intercepts on line X-X from polygon p_2 (obtained from Fig. 4). These loads are to be applied in a horizontal direction. For this purpose we use force polygon $A_7O_7B_7$. Any ordinate in p_7, as H_0R, then is proportional to the product of inertia of the elastic weights between P and the end of the arch rib, with respect to lines P (for example) and X-X. The deflection of point G, along X-X (assuming the left end of the arch free) is

$$\triangle x = P \,.\, H_0R \,.\, H_7 \,.\, H_2 \ldots\ldots (21)$$

H_2 in (21) is obtained from Fig. 4.

Also, this deflection due to the component of the reaction along X-X is,

$$\triangle x = H \,.\, N_4 \,.\, H_4 \,.\, H_2 \ldots\ldots (22)$$

in which H is the required component, and N_4, H_4 and H_2 are obtained from Fig. 4

Equating the two expressions for $\triangle x$, and recalling that the pole distances H_7 and H_4 were both made equal to N_3; also assuming P to be a load of one pound,

$$\therefore H = \frac{H_0R}{N_4} \ldots\ldots (23)$$

If we use the scale $N_4 = 1$ pound in p_7, we can scale directly the reaction component H.

In Fig. 4, the equilibrium polygon p_2' was drawn having its sides at right angles to the force polygon $A_1O_1B_1$. This is repeated in Fig. 12. Thus in p_2' the elastic weights are applied horizontally at their centers of gravity. The angular rotation of point G, due to a load P, assuming the left end of the arch free, is equal to the moment about line P, of all elastic weights between line P and the right end of the arch multiplied by force P. That is,

$$\delta\phi = P \,.\, \overline{M_0L} \,.\, \Sigma w \ldots\ldots (24)$$

in which, as before, Σw is the pole distance of force polygon $A_1O_1B_1$.

And due to the reaction moment M_0, about G, of the left reaction this angle is

$$\delta\phi = M_0 \Sigma w \ldots\ldots (25)$$

equating the two expressions for $\delta\phi$

$$\therefore M_0 = \overline{M_0L} \ldots\ldots (26)$$

That is, the moment about point G of the reaction previously found, due to load $P = 1$ pound, is equal to ordinate $\overline{M_0L}$ to the scale of distance in the drawing.

MOMENT LOADS.

Consider a moment load M (Fig. 12), applied on the arch rib at the vertical L. The vertical deflection of point G due to this moment is,

$$\triangle y = \Sigma Mx \, . \, \frac{ds}{EI} = M \, . \, N_1 \, . \, \Sigma w \ldots\ldots\ldots\ldots (27)$$

in which Σw is again the pole distance in force polygon $A_1O_1B_1$, M is the moment in the rib (assuming the left end free) at any point, x is the horizontal distance from this point to vertical Y-Y through point G, and $\frac{ds}{EI}$ is the elastic weight of the element of the rib at the point considered. For the origin of this expression for deflection, see Part I, Section 11. Therefore in polygon p_1 (Fig. 12) the ordinate N_1 is proportional to the deflection $\triangle y$. The ordinate N_1 is obtained by producing side CD of the equilibrium polygon p_1 to the vertical line Y-Y. N_1 then represents a quantity proportional to the moments of all the elastic weights to the right of line L about line Y-Y. Note that N_1 is also proportional to the moment of all the elastic weights to the left of line L, about line Y-Y. This must be true since Y-Y is by construction the vertical on which lies the center of gravity of all the elastic weights.

Now the deflection along Y-Y of the point G due to the vertical component V, of the reaction due to the moment load M is,

$$\triangle y = V \, . \, N_3 \, . \, H_3 \, . \, \Sigma w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

The quantities in equation (28) are obtained from Fig. 4, and the right side of equation (28) represents the moment of inertia of all the elastic weights about line Y-Y, multiplied by the force V.

Equating the expressions for $\triangle y$ from equations (27) and (28), cancelling out the quantity Σw, and considering $M = 1$ foot pound,

$$\therefore V = \frac{N_1}{N_3H_3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

Therefore the vertical reaction component V is given by equation (29), to the scale used for lengths in the drawing. That is, all three quantities N_1, N_3 and H_3 are to be scaled to the scale of lengths. This is true since the scale for elastic weights has been cancelled out in the cancellation of Σw.

In the same way, the deflection of point G along X-X due to

the moment load M is using polygon p_2, as constructed in Fig. 4 (see repetition in Fig. 12),

$$\triangle x = \Sigma My \frac{ds}{EI} = M \,.\, N_2 \,.\, H_2 \quad \ldots\ldots\ldots\ldots\ldots (30)$$

The right side of equation (30) represents the moment of all elastic weights from line L to the right end of the rib, about X-X, multiplied by the moment M. This quantity gives the desired deflection (see Part I, Section 11).

This deflection as produced by the component of the reaction along line X-X is,

$$\triangle x = H \,.\, N_4 \,.\, H_4 \,.\, H_2 \ldots\ldots\ldots\ldots\ldots (31)$$

The right side of equation (31) is the moment of inertia of all elastic weights about line X-X, multiplied by the required reaction component H. The quantities are obtained from Fig. 4.

Equating the expressions for deflection from equations (30) and (31), and taking $M = 1$ foot pound,

$$\therefore H = \frac{N_2}{N_4 H_4} \ldots\ldots\ldots\ldots\ldots (32)$$

Therefore equation (32) gives the component H of the reaction due to load $M = 1$ foot pound on the arch rib at the vertical L (Fig. 12). In scaling the quantities N_2, N_4 and H_4 the scale of lengths used in the drawing applies.

The angular motion of point G due to a moment load M (Fig. 12) is (see Part I, Section 11),

$$\delta\phi = \Sigma M \frac{ds}{EI} = M \Sigma w_1 \ldots\ldots\ldots\ldots\ldots (33)$$

In equation (33) Σw_1 denotes summation of elastic weights from line L to the right end of the arch, if the left end is free, *i. e.*, if the moment about point G of the left reaction is sought. If the right reaction is sought, Σw_1 denotes the sum of elastic weights from line L to the left end of the arch.

The equal deflection to the above, produced by the moment about G of the reaction due to moment M, is

$$\delta\phi = M_o \Sigma w \ldots\ldots\ldots\ldots\ldots (34)$$

The right side of equation (34) is the product of the reaction moment M_o, and the summation of all the elastic weights of the arch.

Equating as before, the deflections from equations (33) and (34), and considering M a moment load of 1 foot pound,

$$M_o = \frac{\Sigma w_1}{\Sigma w} \ldots\ldots\ldots\ldots\ldots (35)$$

Equation (35) gives the value of the moment about G of the reaction due to a moment load $M = 1$ foot pound at line L, on the

arch. The summations of elastic weights are taken by scaling directly from the load line of force polygon $A_1O_1B_1$, (Fig. 12). Σw_1 is the sum of all elastic weights to the right or left of the load M, depending on which reaction moment is desired, and Σw is the total elastic weight of the arch.

PART III.

APPLICATION OF THEORY TO CONTINUOUS ARCH SPANS.

The application of the method of the ellipse of elasticity to structures on elastic supports was first made by Professor Ritter. In making such application it is necessary to solve two problems:

(1) To find (Fig. 5) the ellipse G representing the condition of the support A of the arch AE resting on the elastic support presented by the combined elasticities of arch BA and pier AC. Having found this ellipse G, it is only necessary to find the stresses in arch AE to use this ellipse as if it were the ellipse of one of the subdivisions of the arch. The remainder of the procedure for arch AE would then be identical with that shown in Fig. 4, Part II, for the single arch span.

(2) Given (Fig. 6) the thrust R from arch AE due to a load on AE, to find how its components R_1 and R_2 are distributed between arch AB and pier AC.

Having solved problems (1) and (2) we have the complete solution of any arch as AB (Fig. 5) resting on elastic supports, both for loads on the arch itself and for loads on any adjacent arch AE.

Solution of Problem I:

Consider the arch AB (Fig. 5) as a single fixed arch, and for purposes of the investigation assume end A free, and having the ellipse of elasticity G_1 where G_1 denotes the total elastic weight of the arch AB. Now the force H_1 which will cause a horizontal displacement of G_1, and therefore of A (the free end), without rotation, will act in the line of the conjugate diameter to Y-Y, the vertical line through G_1. The component of the displacement of G_1 in the line H_1 is (as has been previously shown) equal to $H_1r_1''^2G_1$. Let h denote the horizontal displacement caused by H_1. Then

$$H_1r_1''^2G_1 = h \cos \alpha \quad \text{.........................(1)}$$

Note that $r_1'' = r_1 \cos \alpha$ and $H_1 = H_1h \div \cos \alpha$ where H_1h is the horizontal component of H_1. Substituting in equation (1) for H_1 and r_1'' their values in terms of H_1h and r_1 we have

$$\frac{H_1hr_1^2 \cos^2 \alpha \; G_1}{\cos \alpha} = h \cos \alpha$$

Solving for H_1h, and assuming a horizontal displacement of unity, i. e., h = 1, we have

$$H_1h = \frac{1}{r^2{}_1G_1} \quad \text{.............................(2)}$$

Knowing the direction of H_1 from curves such as shown in Fig. 4, and therefore knowing the value of r_1'', and consequently that of r_1, equation (2) gives us the value of the horizontal component of H_1 which causes a unit horizontal displacement of G_1. Knowing H_1h from equation (2) we can find H_1, of which H_1h is the horizontal component.

Again in Fig. 5, consider point A as the free end of the elastic pier AC, which is assumed symmetrical about the vertical line AC. The force H_2 which will cause a horizontal displacement of point A (or point G_2, the center of the ellipse of the pier) will lie on the conjugate line to the vertical AC and pass through G_2. As the pier is symmetrical about AC, H_2 will be horizontal. The displacement due to H_2 will be equal to the moment of invertia of the elastic weight of the pier multiplied by the force H_2, or to $H_2r^2{}_2\,G_2$. If we assume a unit horizontal displacement then H_2 will be expressed by the equation,

$$H_2 = \frac{1}{G_2r_2{}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In like manner we may determine V_1v, the vertical component of the force V_1 which will cause a unit vertical displacement of end A of the arch AC. This component we find to be

$$V_1v = \frac{1}{G_1r_1{}'^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where r_1' is the horizontal radius of the ellipse G_1.

Also the vertical force V_2 which will cause a unit vertical displacement of point A of the pier AC we find (similarly to the above) to be

$$V_2 = \frac{1}{G_2r_2{}''^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Note that in equation (4) we must know the horizontal radius of the ellipse G_1. Now if we have drawn a set of curves for the arch AB considered as a single fixed arch, such as those shown in Fig. 4, Part II, we can determine the radii of the ellipse along the two axes X-X and Y-Y; since we there have given the perpendicular distance r_1 and r_2 to the tangent points T_1 and T_2. Figure 7 shows a geometrical construction for determining the major and minor axes of an ellipse when two conjugate diameters are given in length and direction.

Let AF and ED be the two conjugate diameters and let r_1 and r_2 be the lengths of the radii of the ellipse which lie along these two diameters. To determine the major and minor axes of the ellipse (the two conjugate diameters which are at right angles to each other) erect the perpendicular BAC to ED, making $BA = AC = r_2$. Bisect angle BGC. Then the major axis of the ellipse lies on the

bisector MN, and the minor axis is RT, at right angles to MN. The length of the semi major axis is

$$a = \tfrac{1}{2}\,(BG + GC) \qquad (6)$$

and the length of the semi minor axis is,

$$b = \tfrac{1}{2}\,(GC - BG) \qquad (7)$$

The length of the radius r_3 of the ellipse in any arbitrary direction making an angle $\propto$ with MN is given by the equation,

$$r_3{}^2 = \frac{a^2b^2}{b^2\cos^2\propto + a^2\sin^2\propto} \qquad (8)$$

By the method given above we can obtain the horizontal radius r_1' required in equation (4) if from previous construction we have given the two conjugate radii along axes X-X and Y-Y, in length and direction (See Fig. 4, Part II).

Referring again to Fig. 5 we note (from the equations given above) that the free end A of the arch AB and the free end A of the pier AC have gone through identical horizontal displacements of unity due to their respective forces H_1 and H_2. Therefore, the point A of the system BAC, due to the action of the resultant H of H_1 and H_2, must have gone through a horizontal displacement of unity without rotation. Also, due to V the resultant of V_1v and V_2, the point A of the system BAC has in like manner gone through a vertical displacement of unity without rotation. The point A, therefore, is displaced along a line passing through the center of gravity G of the ellipse of elasticity of this point, which center of gravity must lie on the intersection of the forces H and V, determined as shown above. Thus we have the location of the center of the ellipse G which constitutes the left support for arch AE.

Again, consider point A as the free end of a single arch BA, and determine the force D_1, which will cause point A (or the center G_1) to rotate through a unit angle about the center G. From previous statements (see the single arch span) we know that the angle of rotation due to a moment D_1d_1 (Fig. 5) acting on the center G_1 (i. e., the end A) is given by the product of the moment D_1d_1 and the elastic weight of the arch G_1. If this rotation is taken as unity then

$$D_1d_1G_1 = 1$$

or

$$D_1 = \frac{1}{d_1G_1} \qquad (9)$$

Also considering A again as the free end of the pier AC, we have in like manner (Fig. 5)

$$D_2 = \frac{1}{G_2d_2} \qquad (10)$$

Equation (10) gives the force necessary to rotate end A about the center G through a unit angle.

Since D_1 rotates G_1 about the center G the point G must be the antipole of line D_1 with respect to ellipse G_1. If we have located point G as explained before we can find D_1 from Section 5, Part I; since D_1 is the antipolar of point G with respect to ellipse G_1. Likewise we can find D_2, the antipolar of point G with respect to ellipse G_2.

Since point A of arch AB and point A of pier AC have gone through identical rotations of unity about point G, due to D_1 and D_2, the point A of the system BAC will go through a unit rotation due to the resultant of D_1 and D_2 and must rotate point G through a unit angle about point G. The resultant force which causes a rotation of point G about itself must lie in the antipolar of point G with respect to ellipse G. This antipolar (from the equation for its position given in Section 5, Part I) must lie infinitely distant from G in the plane of the figure. This means that the rotation of point G is caused by a couple acting on the point, one member of which passes through G and the other (both are infinitely small) lies at an infinite distance from G. But the rotation caused by this couple is identical with that caused by the resultant of D_1 and D_2 found above. Therefore the forces D_1 and D_2 must constitute a couple; since the action of one couple can only be duplicated by another couple. Then $D_1 = -D_2 = D$ (Fig. 5), and the moment of the couple is Dd. Then if G represents the elastic weight of the point G and as assumed above, the moment Dd causes the point G to undergo a unit rotation, we have as before,

$$DdG = 1 \qquad (11)$$

or

$$G = \frac{1}{Dd} \qquad (12)$$

Thus equation (12) gives the elastic weight of point G, which is the center of what is called the "left ellipse" for arch AE, of which ellipse we now can determine both the location and the elastic weight. It remains to determine the major and minor axes of this ellipse, and having done this we will have an ellipse which can be used just as were the subdivision ellipses in Fig. 4 to draw the reaction curves for arch AE. This ellipse G will, if used in these curves, give the true reactions due to the elastic left support of arch AE. Before drawing the reaction curves we must find the ellipse for the right support of AE in the same manner and use this "right ellipse" also in drawing the curves.

In proceeding to find the lengths of the main axes for ellipse G we note that from previous considerations we have two sets of conjugate diameters for this ellipse, viz., line H (Fig. 5) is the conjugate to the vertical line v through G, and line V is the conjugate to the horizontal line through G. Figure 8 gives the geometrical

construction for finding the major and minor axes of an ellipse in length and direction, having given the two sets of conjugate diameters in direction, and the elastic weight of the ellipse, which weight we have from equation (12).

In Fig. 8 let G be the center of the ellipse determined above for point A of the system considered. H and V are the lines of action of the forces found and v and h are the vertical and horizontal lines conjugate respectively to the directions H and V. Assume an arbitrary center C, and describe a circle passing through point G. This circle cuts the straight lines H, v, V, and h, respectively, in the points A, A', B and B'. Draw lines AA' and BB' intersecting at the point O. Draw the diameter OC of the arbitrary circle. Let M and N denote the ends of this diameter. Then the lines GM and GN will be the directions of the required perpendicular axes of the ellipse G.

By analogy equation (2) gives us the radius i of the ellipse G as

$$i = \frac{1}{\sqrt{G \cdot Hh}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

in which Hh is the horizontal projection of the known force H, that is, point T is the point of tangency of line t parallel to line H.

Let T_1 be the point of intersection of line GN and tangent t, and let T'_1T_1 be the projection of the tangent length on axis GN. From a known property of the ellipse, if GD is the semi-axis, we have

$$\overline{GD}^2 = GT'_1 \times GT_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

If we describe a circle on T'_1T_1 as a diameter, and draw a tangent GD_1 to this circle, then GD_1 (the length of this tangent) is the mean proportional between GT'_1 and GT_1, from a known property of the circle, or

$$\overline{GD_1}^2 = GT_1' \times GT_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

From equation (14) and (15) we have GD and GD_1.

In Fig. 8 we therefore have a graphical method of obtaining the length GD, i. e., the semi-major axis of the ellipse G. By a similar construction we can obtain the semi-minor axis GD'.

These axes are to be used just as are the axes of any of the subdivisions of the arch in Fig. 4 in drawing the curves there given for the arch AE (Fig. 5).

Solution of Problem 2:

We now have the ellipse G ("left ellipse") for point A, and can obtain a similar ellipse for point E, the "right ellipse" for this point, by combining the ellipses of pier EJ and arch EF as shown for point A. With these two ellipses and those of the subdivisions of arch AE we can draw the reaction curves as in Fig. 4, giving the effects of loads on arch AE itself. In Problem 2 we are to find the effect of a thrust R (Fig. 6), coming from arch AE, upon arch BA and the pier AC.

Let G_1 (Fig. 6) be the left ellipse of free end A of the arch BA. This ellipse is obtained just as in Fig. 4, by combining the ellipse G_3 of the left support (obtained by the method of Fig. 5) with the ellipses of the subdivision of the arch BA, just as if G_3 were also the ellipse of a subdivision. Also let G_2 be the ellipse of the pier AC.

Now the thrust R coming from the arch AE can be resolved into components, the one R_1 acting on the ellipse G_1, and the other R_2 acting on the ellipse G_2. In other words, R_1 acts on the free end A of arch BA, and R_2 acts on the free end A of pier AC; while the resultant R acts on the resultant ellipse G, obtained as in Fig. 5 by combining ellipses G_1 and G_2.

The point A of the system BAC must go through the same displacement under the action R as the point A of arch BA and the point A of pier AC do under the action of their respective forces R_1 and R_2. Consequently the three forces R_1, R_2 and R must correspond to the same center of rotation; *i. e.*, if D is this center of rotation then point D must be the antipole of R_1 with respect to ellipse G_1; also of R_2 with respect to ellipse G_2; and also of R with respect to ellipse G.

Since we have all the ellipses G_1, G_2 and G previously determined, and we also have the position of R from reaction curves (as in Fig. 4) drawn for arch AE, we can find D, the antipole of R with respect to ellipse G. Having D, we can find the position of the antipolar R_1 of point D with respect to ellipse G_1, and R_2 the antipolar of D with respect to ellipse G_2.

From previous statements we know that the force R_1 will rotate point G_1 (or point A) through an angle $R_1d_1G_1$, in which G_1 is the elastic weight of the ellipse G_1, and d_1 is the perpendicular distance of point G_1 from line R_1. Also R_2 will rotate ellipse G_2 (or point A) through an angle $R_2G_2d_2$. Likewise the resultant R will rotate ellipse G (or point A) through an angle Rdg. Since these angles of rotation must all be equal, we have

$$RdG = R_1d_1G_1 = R_2d_2G_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Since R_1, d and G are known in value, we have in equation (16) a means of finding the value of R_1 and R_2, as the distances d_1 and d_2 have been determined in finding the location of R_1 and R_2, as explained above. We have therefore in R_1 and R_2 the effect of the components of R on the arch BA and the pier AC, respectively.

Consider in (Fig. 9) the arch IB. To draw the curves as in Fig. 4 for this arch we would combine the ellipses of the subdivisions of the arch IB with the ellipse G_6 of the right support of IB, getting the resulting ellipse G_9 of an arch with one elastic support (B) and one fixed support (I). That is to say, the curves of Fig. 4 would be drawn by combining ellipse G_6 with the ellipses of the subdivisions of IB, just as if G_6 were itself a subdivision ellipse.

To obtain first the ellipse G_6 it is necessary to start at the right

end E of the entire system. First combine ellipse G_1 of the original arch AE with ellipse G_3 of the pier AC, obtaining G_2 by the method of Fig. 5. G_2 is the right ellipse of point A. Now using G_2 as the ellipse of a subdivision of arch BA combine this ellipse with the remaining subdivisions of BA, by the method given for the single arch span, obtaining G_5, the right ellipse of arch BA. Again using the method of Fig. 5 combine G_5 with G_7 (the ellipse of pier BL) to obtain G_6, the right ellipse of point B. Having G_6 we can draw the reaction curves for arch IB for loads on the arch itself.

For the effects of loads on arch AB upon arch IB and pier BL, we require the left ellipse of point B, obtained by combining ellipse G_7 of the pier BL with the original ellipse of Arch IB, by the method of Fig. 5.

The effect of a load placed on arch AE, upon arch IB and pier BL is obtained by first getting the effect on arch BA, and then subdividing the thrust on AB between IB and BL, both effects being obtained by the method of Fig. 6.

For the effect of a load on arch AE upon arch AB we require the left ellipse G_4 of point A. To obtain G_4 combine first ellipse G_7 of pier BL with the subdivisions of arch IB by the method of Fig. 5, getting the left ellipse G_8 of point B. Now combine G_8 with the subdivision ellipses of arch AB by the method of Fig. 4 to obtain G_5l (not shown), the left ellipse of arch AB. Again by the method of Fig. 5 combine G_5l with G_3, the ellipse of pier AC, and we have G_4 the left ellipse of point A, by the use of which we can obtain the effect on arch AB of loads on AE.

For investigating the center arch AB, we first find the left ellipse G_8 of point B, as already explained, and the right ellipse G_2 of point A, in a similar manner. Using G_2 and G_8 and the subdivision ellipses of arch AB we can draw the curves of Fig. 4 for the right and left reactions of arch AB. The determination of the effect of loads on AE or IB upon arch AB has already been explained.

The writer wishes to acknowledge with thanks the helpful suggestion of Messrs. M. D. Kolyn, N. M. Stineman and J. M. Sorensen of the Chicago, Milwaukee & St. Paul Railroad during the work of gathering data for the foregoing paper.

DISCUSSION

PROF. S. C. HOLLISTER

In the speaker's opinion the author of the paper on the application of the theory of the ellipse of elasticity to elastic piers should be commended for bringing to the attention of American engineers the simplest method thus far known for the analysis of arch systems continuous over elastic supports. He should further be commended for making available in English the work of Professor H. Lossier in extending Dr. Ritter's use of the ellipse of elasticity to structures of this nature. As the author states, the translation

of this important contribution to the science of engineering is given in Part 3 of the paper under discussion.

It is hoped the discussion which the speaker shall present will throw light in perhaps a more rigorous manner upon the physical conception of the ellipse of elasticity and its function in representing elastic deformations and the facility which its use renders possible in the computation of deformations and stresses existing in statically indeterminate structures. The speaker will first present the phenomena of deformation of an element of a beam. The ellipse of elasticity will then be defined, after which it will be applied to the beam element to show the aid it offers in studying the phenomena of deformation. Later certain applications will be made to the deformations of the elastic arch.

Figure 1 shows an element of a beam defined by two cross sections, C and C', spaced an infinitesimal distance, ds, apart. Let any randomly directed force R be acting upon the element so that its entire effort is applied upon the face C. For convenience in studying the deformation of the element under the action of this force, we will assume the face C' to be held rigidly fixed in space so that any movement of the face C may be described relative to the position of the face C'.

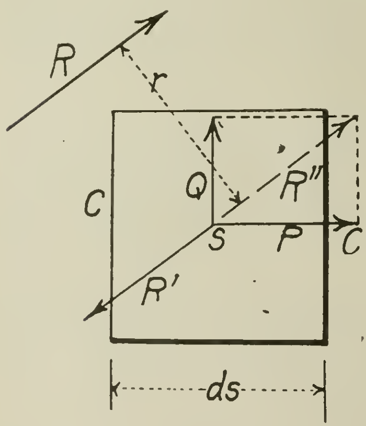

Fig. 1

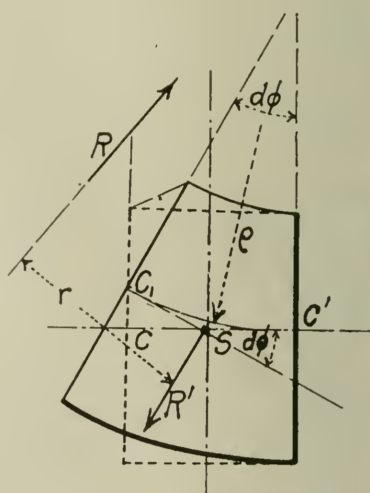

Fig. 2.

The forces R' and R'', equal and opposite to each other, and acting along a line parallel to the line of action of the force R, may be applied at the center of gravity of the element without disturbing its equilibrium. The force R'' may be resolved at the center of gravity of the element into components P and Q, acting respectively along the vertical and horizontal axes of the element. The forces R and R', acting at a distance r apart, form a couple exerting a moment $R.r$ on the section C. The force Q is an upward shearing

force. The force P is a compressive force. The deformation resulting from these forces separately and in combination require special consideration.

Figure 2 shows the element acted upon by the separate couple formed by the forces R and R' spaced a distance r apart. Face C is obliged to move upward and to rotate somewhat so that point C moves to C_1. It should be here noted that since we are dealing in terms of infinitesimal geometry, C_1S equals CS, or C_1 lies on the arc of a circle whose radius is CS and whose center is S. The angle of rotation $d\phi$ is equal to Mds/EI, in which M is the moment of the couple, E the modulus of elasticity of the material of which the element is made and I the moment of inertia of a cross section of the beam about the principal horizontal axis.

Figure 3 shows the element acted upon by the thrust P. Under this thrust C is obliged to move a distance du to C_2. This distance

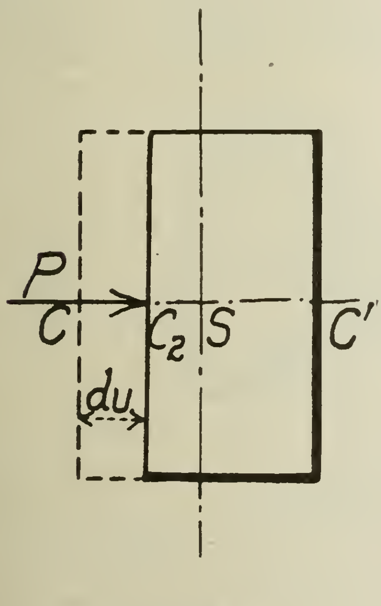

Fig. 3

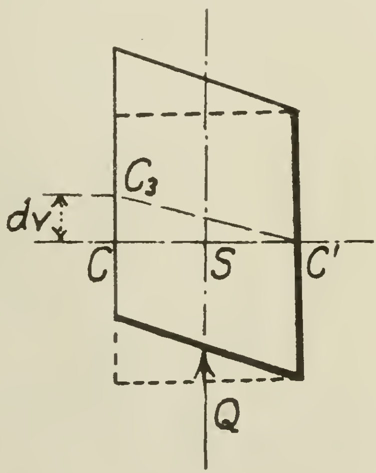

Fig. 4

$du = P.ds/Ea$, in which A is the area of the cross section C of the element. This movement from C to C_2 may be thought of as a rotation about a point whose distance below S in infinite.

When the shearing force acts upon the element, Fig. 4, detrusion results, such that C moves to C_3, a distance of $dv = KQds/GA$, in which K is a coefficient of shear distribution depending upon the cross sectional shape of the element, and G is the shearing modulus of elasticity of the material.

Suppose now we again submit the element to the random force R. Under its action the three motions, bending, thrust and shear must take place. Figure 5 shows these three deformations taking place separately, one after the other. Due to the eccentricity of the force R, its moment about S causes a rotation of the face C about the center S, whence point C is obliged to move to C_1, rotating through an angle $d\Phi$. The thrust component causes C_1 to move a distance du to C_2, whence, due to the shearing force, C_2 moves to C_3.

It should be recalled that each separate motion may be considered as a rotation about some definite point. As a matter of fact, the point C in moving to C_3 does not perform these separate movements, but moves directly to C_3 due to the simultaneous action of

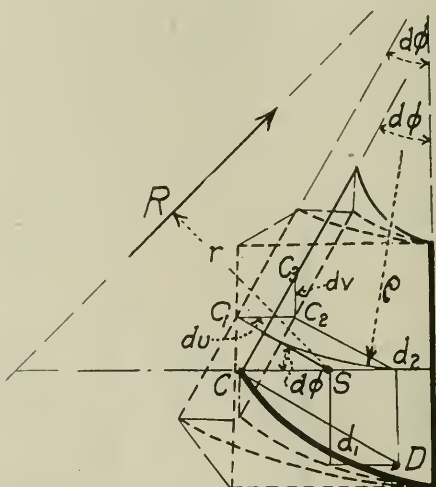

Fig. 5

these three movements. Thus the motion of C to C_3 may be considered a rotation about some definite point.

Now if a body is permitted to rotate about two or more points at the same time, these simultaneous rotations are equivalent to a single rotation about the center of gravity of the separate centers of rotation, if each be loaded with its angular value of rotation; and the magnitude of this single rotation is the algebraic sum of the separate rotations. If there are but two separate centers about which rotation takes place simultaneously, the center of rotation lies on the line joining these two centers. The segments into which this line is divided by the center of resultant rotation are inversely proportional to the separate adjacent angles of rotation.

Returning now to Figure 5, the movement CC_1 was a rotation about point S. The rotation C_1C_2 is about some point on the vertical axis below S at infinity. By the principle just stated, the combined rotations of C moving to C_2 will take place about some point between infinity and S, as, for instance, d_1. Now if we add to this

rotation about d_1 the rotation C_2C_3, which, as we have already noted, was a rotation about some point to the right and at infinity, we will find a rotation about some point lying on a horizontal line through d_1 and to the right thereof.

If we combine the rotations CC_1 and C_2C_3, we would find a rotation taking place on the horizontal axis to the right of S, as, for instance, d_2. If we add to this rotation about d_2 the rotation C_1C_2, which we have noted is a rotation about some point at infinity below S, we would arrive at a rotation about some point on a vertical line through d_2. Since the point of intersection of the horizontal line through d_1 and the vertical line through d_2 is D, this latter point, D, must be the center of rotation of point C in moving to C_3.

Suppose a certain ellipse is constructed whose minor semi-axis, i, is equal to the radius of gyration of the cross section of the beam element about a horizontal axis and whose major semi-axis is equal to $i' = i. \sqrt{KE/G}$. Since the proportions of this ellipse depend solely upon the elastic dimensions of the element, it has been aptly named by Culmann the ellipse of elasticity of the element.

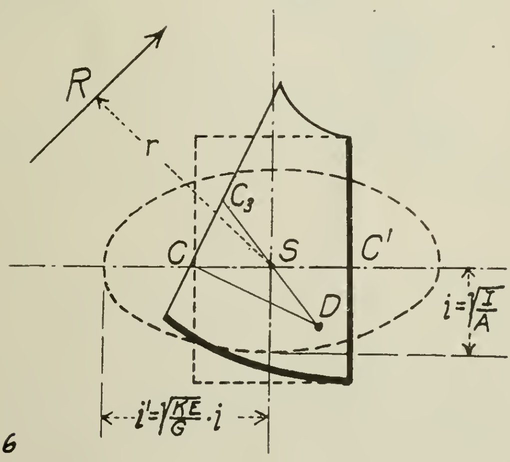

Fig. 6

Let us draw the ellipse of elasticity for the element which we have been considering, and let the force R be acting upon the face C of the element, causing as before a simultaneous rotation of the face C about the center of rotation D. Omitting for the time the mathematical proof, it can be shown that the point D about which the rotation takes place due to the force R is in reality the antipole of the line along which the force R is acting with respect to the ellipse of elasticity. This, then, is the important physical conception of the part played by the ellipse of elasticity in defining elastic phenomena.

Thus far the ellipse of elasticity which we have considered has been for an elementary length, ds, of the beam. When the portion

of the beam considered is of a finite length, $\triangle s$, the minor semi-axis is

$i=\sqrt{I/A},$ as before, and the major semi-axis

$$i'=\sqrt{\frac{s^2}{12}-\frac{KEI.}{GA}}$$

If the deformation due to shear is to be neglected, as may be properly done in the design of ordinary arch structures, but not necessarily in structures of other form, the ellipse of elasticity has its major semi-axis altered by introducing into the above equation for i' the value $G=\infty$, and the expression reduces to $i'=0.289\triangle s$.

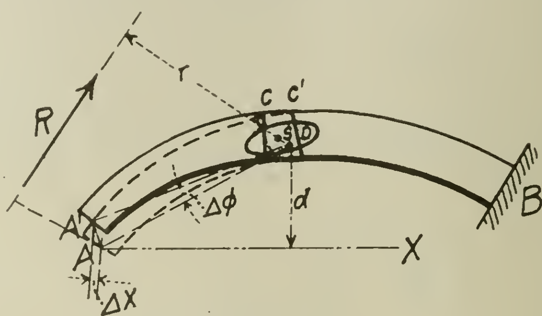

Fig. 7

It will be interesting to apply the ellipse of elasticity to an arch rib. Figure 7 shows an arch rib fixed at B with the outer end A free to move in space. It will be assumed that the finite element CC' is the only elastic element in the rib, the portion of the arch to either side being infinitely rigid. Suppose now that the free end A is acted upon by a force R. Since the portion AC of the arch is infinitely rigid, the motion of the end A is necessarily proportional to the motion of the face C of the elastic element. Let us construct the ellipse of elasticity for this single element. D is the antipole of the line upon which the force R is acting, with respect to the ellipse elasticity of the element. Face C, according to the principles already developed, rotates about the anipole D; and since A and C are rigidly connected, the end A likewise rotates about the antipole D. Since the rotation due only to pure moment acting upon the element CC' has for its center of rotation the point S, the moment of the force R upon the element is equal to the product $R \,.\, r$. The angle through which the end A rotates about the antipole D is equal to

$$\triangle\Phi=R\,.\,r\,.\,ds/EI$$

Through the free end A let any line be drawn, as AX. Then

the component in the direction AX of the rotation of A to A' about D is equal to

$$\triangle x = R \,.\, r \,.\, d \,.\, d/EI$$

It will be interesting to compare this with the usual formulæ for component deformations. The common expression according to the theorem of deformations is

$$\triangle x = M \,.\, y \,.\, ds/EI$$

Applying this to the figure, y would equal the distance of S from the line AX. It will be noted, however, in the formula which we have set up that we do not use the distance between S and AX, but instead use the distance of D from the line AX. The reason for this is that we have considered not only the deformation of the rib due to flexural stresses, but have added as a simultaneous consideration the deformation due to rib shortening or to shear, or to both. These last two deformations are by the ordinary methods treated as superimposed effcts, whereas, in the method under discussion we simply alter the form of the ellipse of elasticity to include them and proceed with the analysis.

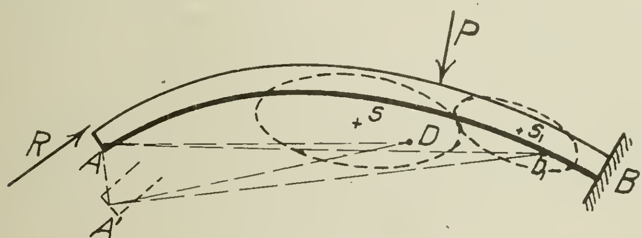

Fig. 8

Suppose now that we consider the deformation of an arch when it is elastic throughout its length. (Fig. 8.) The arch is held rigidly at the end B, with the end A free to move in space. Suppose a vertical load P be applied at some point in the arch. The portion between P and B, being elastic, will deform, and the cross section at P will rotate about the antipole of the force P with respect to the ellipse of elasticity drawn for the portion PB. Since the portion of the arch from A to P is, at present, not loaded, no deformation in it takes place, and the motion of the point A is necessarily a rotation about the antipole D_1 of the ellipse of elasticity for the portion PB. Now it is desired to apply a force R to the end face A to return it to its original position. Since the obliquity of the force R may cause shear and thrust, and its eccentricity on the plane A may produce a moment, the arch may then become a fixed arch carrying a single load P. This force R will cause a deformation in the elements not only between P and B, but likewise between A and P, since it will cause

a rotation about the point D, the antipole of the line of action of the force R with respect to the ellipse of elasticity for the whole arch AB. This gives the physical conception of the results which are desired in the graphical construction given in Part 2 of the author's paper.

It is interesting to note the effect of moderately elastic piers upon the maximum stresses in the elastic arch ring which they support. Some computations made by Professor Lossier give some very significant comparative results.* He analyzed a single semicircular fixed masonry arch having the following proportions:

Span	84.8′
Rise	42.4
Thickness at Crown	4.26
Thickness at Skewback (elevation of 30° above chord)	8.53

Maximum stresses in the arch ring were determined for a uniform live load over the whole span.

A second structure was then analyzed consisting of five spans of the same dimensions as that above, resting on four masonry piers and having the outer ends fixed. These intermediate piers were sixty-six feet high and seventeen feet thick at the top, with an average batter of 0.055 to 1. Maximum fiber stresses were then computed for the central arch when that span was loaded with the same uniform live load applied to the single span above. A third structure was then analyzed. This system consisted of five spans as in the preceding case, but in this case the piers were 164 ft. high, having the same thickness at the top and the same batter as those in the above case. Maximum stresses were obtained for the central arch when that span was loaded with the same uniform live load previously applied.

A comparison of the results of these three cases showed that the maximum stresses found in the case in which the piers were 66 feet high,—or in other words, whose height was about four times their thickness,—were 1.67 times as great as the maximum stress found in the single fixed span; and the maximum stress found under the case in which the height of the piers was about ten times the thickness at the top was a little more than double that found in the single fixed span. Practically the same results were found when the five-span system was altered to one of three spans whose arches and piers had the same dimensions as the cases given above.

Whereas these results have been given here with reference to the slenderness of the piers, there is no strict law existing between the maximum stresses in elastic structures and an expression for the slenderness of the piers, since the form and dimensions of the arches of the system produce large effects in themselves. The conclusions drawn from the above computations, therefore, should in general be used only to point out the seriousness of consideration of elastic piers or elastic supports of any kind.

*H. Lossier: Calcul des Ponts en Maconnerie a Plusieurs Arches, le Genie Civil, LIII (1908), No. 16, p. 268.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings

Meeting No. 973, June 4, 1917

This was a regular meeting of the Society and was called to order at about 8 p. m. by President Burt, with about fifty members and guests present. The President announced the resignation of Mr. B. E. Grant as Acting Secretary of the Society and the election, by the Board of Direction, of Mr. Edgar S. Nethercut to fill his place.

The President also announced that Mr. Ernest McCullough, trustee of the Society and a member of the Board of Direction, had been called to France on active service with the American Red Cross, and because of his absence from Chicago had resigned as trustee of the Society. The President stated that the Board of Direction had elected Mr. G. C. D. Lenth to fill the remainder of Mr. McCullough's unexpired term.

The President announced that the following had been elected to the grades indicated:

No. 30—Herman N. Simpson, Chicago (Transfer from Student) ....Junior Member
No. 31—William G. Born, Chicago............ Member
No. 32—Chason W. Brooks, Chicago (Transfer from Associate) .... Member
No. 33—Roland S. Fend, Chicago............ Member
No. 35—Hubert V. Stephenson, Chicago............Associate Member
No. 36—Charles A. Miller, Jr., Chicago............Affiliated Member
No. 37—John D. Barber, Chicago............ Member

The President then introduced the speaker of the evening, Mr. H. R. Abbott, M. W. S. E., who presented his paper on "Intercepting Sewer Construction in the Northern Part of the Sanitary District of Chicago," which was illustrated by lantern slides. Discussion followed from Messrs. Langdon Pearse, L. K. Sherman, J. W. Mabbs, G. C. D. Lenth and B. E. Grant.

The meeting adjourned about 10:30 p. m.

Meeting No. 974, June 11, 1917

The meeting was called to order at 7:30 p. m. by Vice-Chairman Hudson, of the Hydraulic, Sanitary and Municipal Section, with about seventy-five members and guests present.

The Acting Secretary announced that a Mechanical Engineering Section of the Society was being organized and asked for signatures on the petition for it's formation.

The Chairman then introduced the speaker of the evening, Mr. Rudolph Hering, who presented his paper on "Refuse Disposal," which was illustrated by lantern slides. Discussion followed from Messrs. Charles B. Ball, John Ericson, C. H. Cenfield, W. E. Williams and Dr. J. J. Morgan.

The meeting adjourned at 10:30 p. m.

Meeting No. 975, June 18, 1917

The meeting was called to order about 8 p. m. by President Burt, with about 175 members and guests present. This meeting was a smoker and devoted to patriotic speeches and entertainment. Music was furnished by the Universal Glee Club, Mr. J. H. Libberton, leader, consisting of thirty members. The music was excellent and added greatly to our enjoyment.

Mr. Guy D. Worcester, of the Great Lakes Naval Training Station, described very fully his experience as a member of a Canadian battery in the trenches in France. These experiences were told in a very pleasing

manner and gave us a very excellent idea of the conditions under which the Canadian army has been serving.

Mr. Harrison B. Riley, president of the Chicago Title and Trust Company and chairman of the Executive Committee of the Citizens' War Board of Chicago, explained the preparations which are being made for meeting the emergency in our country, and gave first hand analysis of the opportunities and responsibilities open to our citizens who will not go to the front.

Mr. H. S. Baker, chairman of the Military Committee of the Western Society of Engineers, gave a resume of the activities of our Society during the progress of the war, as follows:

"What Western Society Members Are Doing to Serve the U. S."

"Our Society has been active in the movement for preparedness since early in the great war. Soon after the start of the war a resolution was introduced at one of our regular meetings by W. W. DeBerard, reciting the services of engineers in the warring countries and the need for engineers to prepare to serve our own country. A committee was appointed which has served with a good deal of intermittent activity since that time. Several meetings were held on military subjects. One was addressed by Col. Judson and others by the officers of the Illinois National Guard engineers.

"Early in 1916 the Joint Committee on Military Engineering was formed, with which we co-operated, and arranged a series of entertaining lectures on military subjects which kept up our interest and gave us a pleasant feeling of doing something.

"Several of our members spent a pleasant summer in the vicinity of San Antonio, Tex., in their country's service, last year, and upon our return found that the Society had agreed to assist the United States Engineer Officer, Colonel Riché, in arousing interest in the Engineer Officers' Reserve Corps, and by securing for him additional information regarding candidates. Meetings were held and a considerable interest in the corps was developed.

"Our committee undertook to secure the information desired in regard to candidates, but the work soon grew beyond our ability to handle and the membership of the Society was called on for help. The response was gratifying in the prompt and careful investigation that was given in almost all cases. The Secretary of the Military Training Camps Association for Chicago, Wharton Clay, M. W. S. E., has rendered service of great value.

"Since the declaration of war, some of our members have been called into service on government boards and commissions, while others have enrolled at the training camps. This list of those in the government service includes all I have been able to ascertain. I have probably omitted some names and will be glad to insert them before this list is published, if they are brought to my attention."

B. F. Affleck, Member of Committee on Raw Materials of the Council of National Defense of the United States

E. W. Allen, Captain Engineer Officers' Reserve Corps, Fort Sheridan.

John W. Alvord, Civilian Engineer on cantonment work, Rockford, Ill.

Bion J. Arnold, Member of Naval Consulting Board of the United States, of which he is Chairman of Transportation Committee, Member of Committee on Engineering and Inventions of the State Council of Defense of Illinois, and Major in the Engineer Officers' Reserve Corps.

H. S. Baker, Captain, Construction Quartermaster, Fort Bowie, Fort Worth, Tex.

Victor H. Bell, Second Lieutenant, Engineer Officers' Reserve Corps, Presidio, San Francisco, Cal.

Jos. L. Canby, Second Lieutenant, Company I, Eighteenth Infantry, American Expeditionary Force in France.

W. B. Causey, Captain, Engineer Officers' Reserve Corps, Seventh Reserve Engineers, Atlanta, Ga.

Kenneth M. Copley, Aviation School, Champaign, Ill.

Paul Hansen, Captain, Engineer Officers' Reserve Corps, Chicago, Ill.

Geo. H. Harris, Brigadier General, Nebraska Natianal Guard, Fort Crook.

John F. Hayford, Member of Consulting Board on Aeronautics, Washington, D. C.

Peter Junkersfeld, Major, Engineer Officers' Reserve Corps, Washington, D. C.

Walter F. Maun, Company F, Thirteenth Regiment Engineers, Railway Epeditionary Force, France.

Dabney H. Maury, Major, Engineer Officers' Reserve Corps, Washington, D. C.

Ernest McCullough, Major, Engineer Officers' Reserve Corps, France.

C. C. Saner, Captain, Company A, First Illinois Engineers, Rockford, Ill.

John Stone, Aviation Corps, Ohio State University, Columbus, Ohio.

Daniel A. Tomlinson, Second Lieutenant, First Illinois Engineers, Chicago, Ill.

Murray Blanchard, Captain, Fort Sheridan, Ill.

Homer W. Deakman, Second Lieutenant, Fort Sheridan, Ill.

Rector Egeland, Fort Sheridan, Ill.

E. Webster Evans, Fort Sheridan, Ill.

Henry M. Hedges, Fort Sheridan, Ill.

John R. LeVally, Second Lieutenant, Fort Sheridan, Ill.

Robert Isham Randolph, Captain, Fort Sheridan, Ill.

Wallace A. Sawdon, First Lieutenant, Fort Sheridan, Ill.

Edwin B. Styles, Fort Sheridan, Ill.

George M. Ilg, Fort Sheridan, Ill.

Robert L. Fitzgerald, Engineer Company No. 7, Eleventh Provisional Regiment, Fort Leavenworth, Kans.

Fred Kellam, Second Lieutenant, Michigan Engineer Company, Fort Leavenworth, Kans.

E. J. Blair, Captain, Fort Benjamin Harrison.

Frederick W. Greve, Jr., Fort Benjamin Harrison.

George D. Hardin, Fort Benjamin Harrison.

Byron L. Kelso, Fort Benjamin Harrison.

Wendell S. Merick, Fort Benjamin Harrison.

A. R. Montague, Fort Benjamin Harrison.

Albert L. Smith, Fort Benjamin Harrison.

Wilbur M. Wilson, Fort Benjamin Harrison.

Samuel P. Hendricks, Fort Logan H. Root, Ark.

The committee will continue to secure the names of our members who enter the service, together with the address and rank. These will be maintained on cards in the office of the Society, where they may be referred to.

The meeting was very successful in arousing the patriotic spirit of our members.

The meeting adjourned at 10:30 p. m.

Excursion, Saturday Afterday Afternoon, June 23, 1917

Through the courtesy of the Engineering Department of the Sanitary District of Chicago and the contractors, Messrs. Nash-Dowdle Company, an opportunity was given to the members of the Western Society of Engineers and their friends to inspect the intercepting sewers now being constructed in Evanston, as described by Mr. H. R. Abbott in a paper which was presented before the Society, June 4, 1917.

The party had a special train on the Northwestern Elevated and

arrived in Evanston about 3 p. m. Here we were met by motor buses provided by the contractors and taken first to inspect the material yards of the company, and then to the dumping platforms on the lake front. We were then taken to Shafts Nos. 1 and 2, where an opportunity was given to go down into the tunnels and observe the method of construction. This work is being carried on under light air pressure.

After the inspection of the tunnels, a lunch was served by the contractors and the return trip was made to the city in motor 'buses provided by the contractors.

Mr. George W. Jackson, M. W. S. E., is consulting engineer for the contractors and the work is carried out in accordance with plans and specifications drawn by him. This includes many improvements in tunnel construction.

About 100 members and guests attended this inspection trip, and the party was guided by Mr. H. R. Abbott, M. W. S. E., engineer of the Sanitary District, and his assistants.

Edgar S. Nethercut, Acting Secretary.

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THE 186 FOOT BASCULE BRIDGE OF THE C. & N. W. RY., OVER THE NORTH BRANCH OF THE CHICAGO RIVER AT DEERING

By O. F. Dalstrom, *M. W. S. E.**

Presented March 12, 1917

The C. & N. W. Ry. put in service on July 30, 1916, a new Strauss Heel Trunnion Bascule bridge over the North Branch of the Chicago River, at Deering Station, Chicago. This bridge carries three tracks and spans a channel of 145′ 0″ clear width between fenders, crossing it at an angle of 74 degrees. The rest pier and the front end of the movable span are skewed to parallel the channel. Fig. 1 is a General Plan of the bridge.

The new structure replaces an old double track swing bridge of 176′ length, supported on a center pier. The old bridge was worn out, and it had become necessary to replace it with a bridge of greater capacity and strength, to take care of the great volume of traffic and the heavy power on this line, which is the Railway's main line between Chicago and Milwaukee.

The railway traffic during construction consisted of about 200 trains every 24 hours, about 80% of which were passenger trains. The normal river traffic required from 30 to 100 swings per month, the greatest activity being from July to October. This made it necessary to keep at least one of the two channels continuously available for navigation during construction.

The necessity for maintaining river and rail traffic uninterrupted during construction was a governing factor in determining the type and design of the new bridge. The design adopted possessed the following advantages in construction: (a) The new substructure could be constructed complete with but little disturbance of the old substructure; (b) The temporary structure required was of simple and inexpensive construction, being only a few spans of timber trestle at each end of the old draw span; (c) The new superstructure could be erected almost complete without interruption to traffic; (d) The counterweights could be cast solid in forms supported on the floor of the counterweight pit; (e) The old draw span could be kept in operation continuously during the entire period of construction, maintaining traffic uninterrupted on both river and railway.

*Engineer of Bridges, C. & N. W. Ry. Co.

In addition to the increased facilities for handling the heavy railway traffic, the conditions for river navigation are greatly improved under the new structure. A single channel of 145′-0″ clear width replaces the narrow channel on each side of the old center pier, and this channel is deepened to 21.5 ft. below Chicago City Datum. Water level of bridge varies from 1.6 ft. below to 1.2 ft. above Datum. The vertical clearance under the old span was 16.5 ft. above Datum, and this clearance is increased to 18.25 ft. under the new span, which permits a large proportion of the boats navigating this channel to pass without opening bridge.

SUBSTRUCTURE

The substructure under the tower consists of four steel cylinders 12 ft. in diameter, filled with concrete, and connected at the

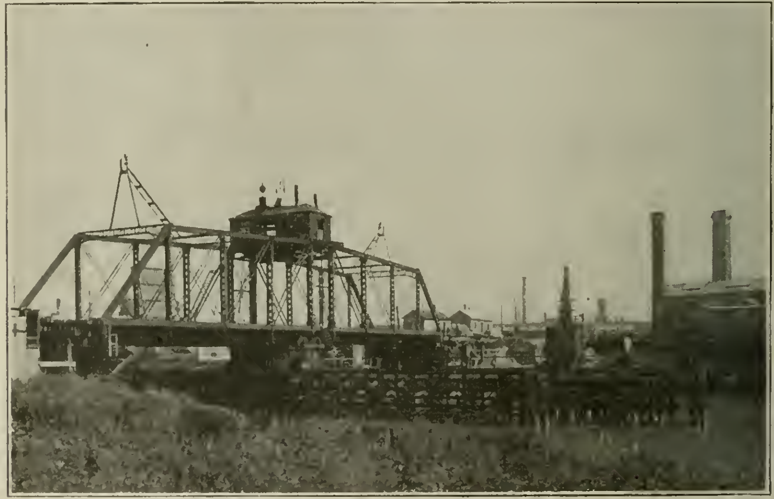

Fig. 2. General View of Old Bridge.

tops by a rectangle of heavy reinforced concrete girders. The cylinders are carried down to rock. The tops are 2′-0″ below Datum, the concrete girders being carried up from this level to elev.+17.25, the level of the superstructure bearings, 6′-9″ below base of rail.

The concrete girders are reinforced with embedded structural steel trusses and with horizontal and vertical reinforcing bars near the surface. The trusses were designed to carry the entire weight of the concrete, together with the superimposed track load where any occurs. The reinforcing bars were provided for local reinforcement and to prevent surface cracks. The longitudinal reinforcing in the bottom of the girders was made heavy to prevent the development of tension cracks.

The girder directly under the heel trunnions is the heaviest of the four, being 8′ 0″ thick and reinforced with two trusses. It carries one end of a 35 foot deck plate girder span, the other end of which rests on an abutment built between the side girders. The other girders in the substructure of the tower are 6′ 0″ thick and contain only one reinforcing truss each.

With the bridge in the fully open position, the counterweights extend about 14 feet below the base of rail, and their inner surfaces are 8′ 3″ from the centers of adjacent tracks. The operating struts are between the counterweights and the tracks, and when the bridge is fully open they extend about 12 feet below the base of rail. This circumstance made it necessary to build retaining walls just beyond the pier, to hold the embankment, placing the walls inside the limits of clearance required by counterweights and operating struts. To provide the necessary clearance for the operat-

Fig. 3. Temporary Bridge. Excavating for Retaining Walls.

ing struts, the faces of the retaining walls were placed 5′ 8″ from the center of track, for a distance of 15′ 6″ to the rear of the vertical tower post. This brought this portion of each of the walls so close to the track that hand railing could not be erected on top of them without encroaching on the required clearance. To safeguard these sections, platforms were built level with the top and just clear of the face of the wall. One end of each of the platforms was hinged to the tower post and the other end suspended by rods from the framework of the counterweight truss bracing directly above. Gas pipe hand railing was erected on these platforms, just outside the clearance lines. As the bridge opens, the platforms,

swinging around the hinged ends, drop down out of the way of the operating struts, returning to normal position at the top of the wall as the bridge closes.

The rest pier, at the front end of the span, consists of two cylinders, 12′ 0″ in diameter, connected at the tops by a concrete girder 8′ 0″ thick and reinforced with two embedded steel trusses. The details of this girder and its reinforcement are similar to those of corresponding parts of the substructure under the tower.

All cylinders were carried down by open excavation to rock, those under the tower pier about 50 feet below datum, and those under the rest pier about 40 feet. The lower section of each cylinder was fitted with a horizontal steel diaphragm 8 ft. above the cutting edge, to make this section a working chamber. In the center of this diaphragm was a circular opening 3′ 0″ in diameter, over which

Fig. 4. Forms for Rear Substructure and Retaining Walls.

was built up the working shaft, consisting of a steel cylinder 3 feet in diameter. The horizontal diaphragm was rigidly braced to the section of cylinder below, with eight solid webbed radial braces extending from the diaphragm to the lower edge. This edge was heavily reinforced with thickening plates and an angle, to enable it to cut through stiff clay, gravel and hard pan, and to resist crushing by boulders.

The excavation was carried on by men digging inside this working chamber, and the material was hoisted out in buckets through the working shaft. Water was pumped out with a Nye pump let

down into the working chamber and connected by steam hose running up the shaft and out to a steam boiler set on the ground.

The cylinders were delivered at the bridge site riveted up in sections of about 8′ 0″ length. As fast as the cylinder was carried down by the excavation in the working chamber, sections were riveted on above, carrying up the working shaft at the same time as the large cylinder. As soon as a section was riveted on it was filled with concrete. In all but the last stages of the sinking of each cylinder, the concrete gave the weight necessary to overcome the friction of the earth against the sides of the cylinder and carry it down as excavation progressed. As the cylinders approached final depth, it became necessary to add pig-iron on top of the concrete to over-

Fig. 5. Rear Substructure. Head House in Place for Sinking Cylinder.

come this friction and make them sink. Following is an extract from the log of the Great Lakes Dredge and Dock Company, covering that portion of the work which developed the greatest skin friction of the cylinders:

No. 1—Caisson South Abut. (East Front Well), 8:00 A. M., Nov. 10, 1915.

Stopped at Elev.—41.22.
56 ft. of shell in place.
40 lin. ft. concrete in place.
Cutting edge undercut 6 ft.

Load—Steel shell	43,190	lbs.
Concrete	593,600	lbs.
	636,790	lbs.

Area—37.7′x41′=1,546 sq. ft. for 41 ft. penetration.
Skin Friction=412 lbs. per sq. ft. and shell stopped sinking.
Later, at 8:45 A. M., after 100 tons of pig iron was added to load, shell dropped to bottom of excavation, about 6 ft., to Elev.—48 and continued moving.

Load—Steel shell	43,190	lbs.
Concrete	593,600	lbs.
Pig iron	200,000	lbs.
	836,790	lbs.

Fig. 6. Cylinder Loaded with Pig Iron to Make It Sink.

Area—37.7′x48′=1,809 sq. ft. for 48 ft. penetration.
Skin Friction—463 lbs. per sq. ft.

No. 3—Caisson South Abut.—West Front—8:00 A. M., Nov. 10, 1915.
Moving at Elev.—43.93′.
56 ft. of shell in place.
40 lin. ft. of concrete in place.

Load—Steel Shell	43,190	lbs.
Concrete	593,600	lbs.
	636,790	lbs.

Area—37.7′x44′=1,658 sq. ft. for 44′ penetration.
Skin Friction=384 lbs. per sq. ft.

No. 2—Caisson S. E. Rear stopped at Elev.—26 with friction of 304 lbs. per sq. ft. Started again when loaded to develop a skin friction of 516 lbs. per sq. ft.

When the cylinders reached final position on rock, the surface of the rock was leveled off and cleaned and the work chambers and shafts filled with concrete. In the top of each of four of the cylinders were set vertically 18 track rails 12 feet long, embedded half their length in the cylinder, the other half projecting above the top to be built into the concrete girders to strengthen the bond between cylinders and girders. These rails were omitted from the

Fig. 7. Rear Substructure Complete.

two rear cylinders, as the vertical posts of the towers were embedded in the tops of these cylinders and, in addition to doing duty as tower posts, served the purpose for which rails were provided in the other cylinders.

As the concrete girders were designed to extend down 2′ 0″ below datum, it was necessary to enclose the piers in coffer dams to construct the lower portions of the girders. A dam of sheeting and puddle was constructed on the river side of each pier and run shoreward well into the river bank. The bank formed the fourth side of the dam. The reinforced concrete girders were built in place inside this dam, on top of the cylinders, first erecting the structural

steel trusses, building the forms around them, assembling the reinforcing inside the forms, and proceeding in the usual way with the filling of the forms with concrete.

SUPERSTRUCTURE

The superstructure is here arranged under four heads for convenience in description:

(a) Movable span and counterweight. This includes all moving parts, except machinery.
(b) Tower.
(c) Operator's house.
(d) Machinery, power and operating equipment.

Fig. 8. Erection Tower and Material Track.

MOVABLE SPAN

The movable span, being skewed at one end to fit the angle of the channel, has trusses of unequal length, the long truss being 186′ 0″ from center of main trunnion to center of bearing at front end.

The live load used in designing was Cooper's Class E-55, applied as follows:

Stringers—Track fully loaded.
Floor beams—Full load on middle track and ⅝ of full load on two outside tracks.
Trusses—Three-quarters of full load on all three tracks.
Design, detail and material to be in accordance with C. & N. W.

Ry. Specification for Steel Bridges, supplemented by special specifications prepared by the Strauss Bascule Bridge Company to cover all features not covered by the C. & N. W. Ry. specifications.

The counterweight consists of two reinforced concrete wings, one on each side of the bridge, outside of the clearance lines. They are cast around the framework of the counterweight trusses, which are mounted on trunnions set in heavy bearings at the top of the tower. The aggregate used in the counterweights was Fayalite, a very heavy and hard rock obtained in Northern Illinois. The con-

Fig. 9. Tower and Part of Bascule Span Erected.

crete was mixed in different proportions for the two wings, in order to keep the volume and outline the same for both, but to give to each wing the weight necessary to counterbalance the corresponding side of the skewed movable span. The concrete in the counterweight for the short truss weighed about 160 pounds per cubic foot at 20 days; that for the counterweight of the long truss about 168

pounds. The composition giving these weights was almost exactly 1:2:4 for 168 lbs. and 1:3:5 for 160 lbs. per cu. ft.

The detail of the counterweights provided a number of horizontal cylindrical pockets for adjusting blocks. These pockets are 1′ 11″ in diameter and extend all the way through the counterweight, excepting where interrupted by the members of the counterweight trusses, where they extend only 1′ 11″ from the surface. Cylindrical concrete adjusting blocks 1′ 10″ in diameter and 1′ 8″ to 1′ 10″ long were cast for these pockets. The volume of the pockets constitutes about 7% of the total volume of the counterweight, and it was estimated that the counterweights would balance the span when half of the pockets were filled with adjusting blocks, giving a possible adjustment of 3½% of the total amount of coun-

Fig. 10. Erection Nearly Completed, as Bridge Appeared the Day Before It Was Put in Service. Old Bridge Shown Still in Service.

terweight either way from the estimated requirement. After bridge was completed and the counterweights adjusted, these pockets were all sealed with cement mortar spread on wire netting on frames set in the ends of the pockets. This effectually conceals the pockets and gives the counterweights the appearance of being solid throughout.

On account of the great weight of the moving parts, the trunnions are of unusual size. The trunnions at the top of the tower, carrying the counterweight trusses, are 24″ in diameter. The heel trunnions are 17″ in diameter and those at the ends of the connecting links are correspondingly large. The four trunnions on each side of the bridge are so arranged that the four lines connecting

their centers form a true parallelogram, a condition essential in applying the principle of counter-balance of this type of bridge. The counterweight, while revolving around a center different from that of the moving span, always moves through the same degree of angle as the span, but in the opposite quadrant of the circle.

TOWER

The tower carries at its highest point the two trunnions on which are mounted the counterweight trusses. The size and general outline of the counterweights determined the height at which

Fig. 11. Cutting Out Middle Portion of Old Span to Make Way for Lowering the New Bascule Span.

the supporting trunnions must be placed to keep the counterweights above the level of the water in river when in their lowest position. This fixed the general dimensions of the tower, which is 50′ 5¼″ from base of rail to center of counterweight trunnion, and its span 55′ 6″ between front and rear bearings on the substructure.

MACHINERY, POWER AND OPERATING EQUIPMENT

The machinery was designed to open the bridge the full angle of 87 degrees in one minute, against an unbalanced load of 2½ lbs. per square foot of floor area of moving span, acting normal to the

floor of the bridge. The specifications also provided that machinery should be of the required strength, and the power sufficient, to open the bridge slowly against an unbalanced snow load of 10 lbs. per square foot of floor area, combined with an unbalanced wind pressure of 10 lbs. per square foot of this area; also, to hold the bridge stationary in any position against the snow load of 10 lbs. per square foot combined with a wind pressure of 15 lbs. per square foot.

The power installation consists of two 150 H. P. motors coupled in parallel. The power is alternating current, 3 phase, 60 cycle, 440 volts.

Fig. 12. New Bridge in Position Ready for Trains. Ends of Old Bridge Still Resting on Blocking, as Left When Middle Portion Was Removed to Permit Lowering New Span.

Auxiliary power is provided in the shape of a 45 H. P. high speed gasoline engine connected through reduction gearing and reversible friction clutches with the spur gear driven by the motors. This arrangement makes the motors run idle when operating the bridge with the engine. The solenoid brakes on the motors, which are normally released only when current is driving the motors, are held in release position during operation of engine, by special mechanism provided for this purpose. An auxiliary hand brake is pro-

vided for control of bridge when operating with engine. The emergency brakes described below are also available for this purpose.

To protect the operating machinery from the effect of applying brakes at the motor shaft, emergency brakes operated by compressed air are mounted on the operating shafts, enclosing the operating pinions. When set, these brakes seize the operating struts and transmit the action of the moving parts direct to the bearings of the operating shafts, without passing it through a single gear of the machinery. Compressed air for these brakes is furnished by a small electrically driven compressed air unit which is automatically controlled by the pressure of the air in the storage tank.

Fig. 13. Another View of New Bridge Just After Bascule Span Was Lowered.

Following is a table of quantities in the superstructure:

Structural steel—	
Moving parts	1,769,000 lbs.
Tower	757,800 lbs.
Machinery and trunnions	255,800 lbs.
Total	2,782,600 lbs.
Concrete in counterweight	2,360,000 lbs.

The upper part of the tower, above the clearance line of 22′ 0″ above top of rail, is occupied by the operator's house, which contains the operating machinery, power installation, interlocking plant, and all the equipment for operation and control.

The design of the operator's house was given considerable study

by the Railway Company's engineering department. The outside dimensions of the house were fixed by the clearance required in all directions—below by the clearance required above the tracks; in all other directions by the moving parts of the bridge and by the tower bracing. The operator's floor occupies the rear half of the house, and is placed 3′ 5″ above the machinery floor. This gives the operator a clear view above the machinery from any point on the operating floor. The location of windows, positions of installations in the house, and the arrangements of operating equipment, were all made to conform to the requirements for unobstructed view from the operator's position behind the controllers, and for quick and easy access to all operating levers. The air tanks, water tanks, and most of the piping were suspended from the roof to avoid overcrowding the floor space.

The steel framework under the house is protected from the locomotive blast by concrete covering. The walls and roof are of wood, protected with fireproof asbestos covered metal. The inside is finished with beaded wainscoting up to the level of the window sills, and with beaver board above that level. All windows are double, the removable sash being on the inside to facilitate placing and removal. It is intended to have the inner sash in place during the winter only, to prevent excessive radiation by the large glass surface; and to prevent frost coatings on the glass, which would obstruct the operator's view.

The house is heated by a hot water heating plant. Running water is provided by direct connection with the city water main. Lavatory and sanitary conveniences are provided, with soil pipe discharging into the river below the water level.

ERECTION

The bridge was erected in open position, the usual method of erecting this type of bridge where traffic must be maintained during erection.

The material for the superstructure was delivered at the bridge site, for erection, on a spur track built along the west side of the new substructure and as near to it as practicable. A timber tower spanning the main tracks was built just behind the proposed location of the bridge tower. On top of this timber tower a stiff leg derrick was erected, on the side adjacent to the material track. The timber tower and the derrick were designed to handle material direct from cars on the track, and set it in place in the bridge. From this first position of the derrick, the bridge tower, the operating machinery and the first three panels of the movable span, except the floor member of the lower panel, were erected. These floor members were omitted to avoid obstructing rail traffic.

At this stage of the work the derrick was moved up to a higher level and set in position on the highest point to which erection had been carried. From this second position the erection of the structural material was completed, except the members omitted to avoid

obstructing traffic. The deck and track on all except the lower panel were also put on with the bridge in the open position.

The parts which it was not practicable to erect while traffic was still being carried on the old bridge, included the floor members of the first panel, some of the bracing between counterweight trusses, and certain minor parts at the front end of the span. The plan of erection adopted therefore provided for the suspension of traffic on railway and river while the old bridge was taken out and the new bridge put into service. To make this interruption as short as possible, every member that could be erected was put in place and riveted up before traffic was suspended. Power transmission connections were completed and the operation of the machinery was tested under power. The bridge was also moved through a small angle and the counterbalance adjusted. Sunday, July 30th, was selected as the day for putting the new bridge in service. A schedule of operations for the day was prepared and issued to all officials in charge of any part of the work, providing for the suspension of traffic on the river at midnight, Saturday night, and on the railway at 12:23 Sunday morning.

Following is the schedule:

Schedule of Work on July 30th, 1916, for Placing the New 3-Track Bascule Bridge in Operation.

Suspension of Traffic:

Railway traffic over the old bridge will be suspended at 12:23 A. M., Sunday, July 30th, after train No. 301, northbound, has passed.

Railway traffic will be resumed at 4:07 P. M., at which time the new bridge must be in position to let train No. 166, southbound, pass.

Navigation in the river will be suspended from 12:00 o'clock midnight, Saturday night, to 6:00 P. M., Sunday.

Schedule of Operations:

Immediately after traffic has been suspended at 12:23 A. M., the old bridge will be opened and swung over the old pier protection. The order of work outlined below will then be followed:

FIRST PERIOD

(From the suspension of traffic at 12:23 A. M., to the lowering of the bridge at 8:15 A. M.)

By C. & N. W. Ry. Co.'s Forces:

(a) Immediately after the suspension of traffic at 12:23 A. M., division forces will begin removing the track and the timber bridges in the north and south approaches. The iron bridge crew will have a derrick in operation at each approach to handle and load the material removed by the division forces.

The work on both approaches will be started at the same time, one division crew and one iron bridge crew working on each approach.

A work train will be in service at each approach after 12:00 o'clock midnight, until 4:00 P. M., Sunday.

(b) Iron bridge crew will lift the concrete backwall blocks into place. Division forces will place the bed of mortar to set them in, and close up the joints with mortar.

Bridge crew will erect the deck plate girder spans. The spans in north approach will be bolted up for traffic.

The spans on the south approach will be erected complete ready for deck at 5:00 o'clock A. M., and the spans on the north approach at 6:00 o'clock A. M.

(c) The division forces will lay the decks and rails on the approach spans. The rails will be in place on the south approach at 7:00 o'clock A. M., and on the north approach at 8:00 o'clock A. M.,

(d) The iron bridge crew will carry the cast iron bearings for the north end of the bascule span to the north pier, but will not place them in permanent position.

(e) The track elevation forces will begin work at 7:00 o'clock A. M., raising the grade and realigning the tracks on both approaches, beyond the steel spans. Tracks will be laid for double track service.

All work on change of grade and alignment will be completed and the tracks ready for service by 2:00 o'clock P. M.

By the Great Lakes Dredge & Dock Co.:

(f) Immediately after the old bridge has been opened at 12:23 A. M., the Great Lakes Dredge & Dock Co. will block it up on the old pier protection, and cut it apart with the oxy-acetylene flame at such points as necessary to facilitate quick removal of the middle section. This section will be removed down to the level of the treads under the wheels of the turntable.

All material removed from the old bridge will be loaded on a scow furnished by the Great Lakes Dredge & Dock Co. for delivery, at later time, to railway company's cars.

The above work of cutting apart the middle section, removing it and loading it on scow must be completed, and the equipment removed by 7:30 A. M.

By the Kelly-Atkinson Const. Co.:

(g) Immediately after the iron bridge crew has completed its work on the south approach span at 5:00 A. M., contractor will pull in on the east track and erect the bracing between the counterweight trusses, and the bottom laterals in the lower panel of the movable span.

Also, move the bearings for the north end into permanent position on the north pier, but will not anchor them at this time.

All of the above members must be in place and bolted up complete by 8:00 A. M.

At 8:15 A. M. the bascule span will be lowered by electric power.

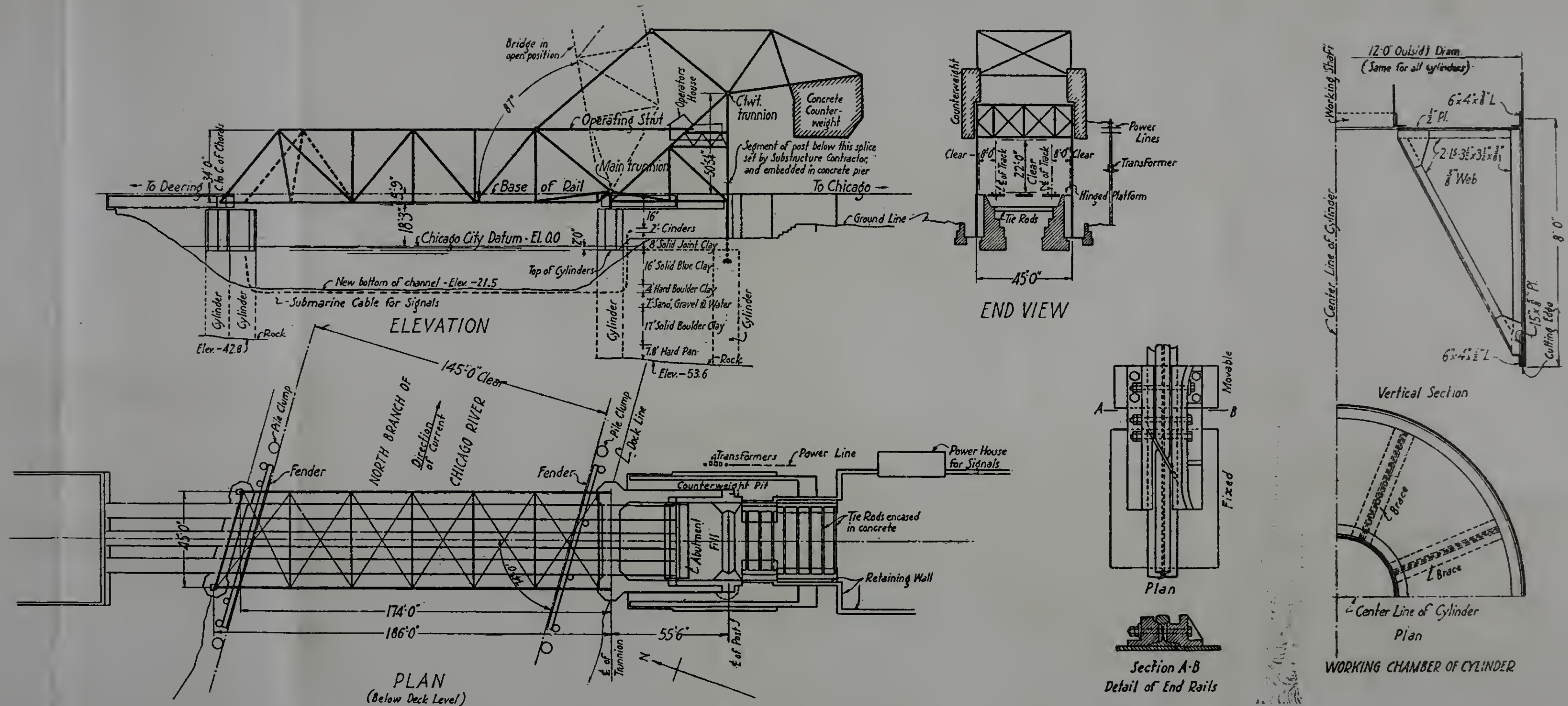

Fig. 1. General Plan of Bridge.

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a]

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SECOND PERIOD

(From the lowering of the bridge at 8:15 A. M. to the resumption of traffic over bridge at 4:07 P. M.)

By the Kelly-Atkinson Const. Co.:

(a) After the lowering of the bridge at 8:15 A. M.:

The bearings on the north pier will be adjusted and anchored.

The floor members in the south panel of the movable span erected and bolted up complete.

Ties and rails in south panel placed.

Holes for end lock casting drilled in the castings on the north pier, and end locks attached and adjusted.

Movable platforms over the counterweight pockets erected and adjusted.

Counterweights adjusted by addition of the necessary number of counterweight adjusting blocks.

All parts at north end of span not in place will be erected and adjusted.

Bridge will be locked by closing end lock with hand operating mechanism.

By C. & N. W. Ry Forces:

(b) The track elevation forces will place the tie plates, align and adjust the rails and spike them to the ties.

Immediately after the last train had passed at 12:23 the old span was swung open and the arms blocked up on the old timber pier protection. Eight oxy-acetylene torches were immediately set to work to cut the old bridge into three parts so that the middle portion could be removed to make way for the lowering of the new span. While the torches were cutting the span apart, a scow derrick was at work on each side of the old span, removing the operator's house, operating machinery and deck. By 7:30 Sunday morning the old span had been cut apart, the middle portion lifted out and placed on scows and the scows and equipment removed from the bridge site. At 8:15 the new span was lowered to horizontal position.

After lowering the bridge, the few remaining members were erected, the deck completed, and the end rails put on and adjusted. At the same time track gangs were realigning the tracks on the approaches and raising them to the established grade. This part of the work could not be completed in time to re-establish rail traffic at 4:07 P. M., the time designated in the schedule, and the time was extended to 6:00 o'clock. By that time the bridge and tracks were in shape for trains and traffic was resumed, after an interruption of less than 18 hours.

SIGNALS

The operating mechanism of the bridge is interlocked with the switch and signal system controlling the traffic on all tracks adja-

cent to the bridge. The system of tracks controlled by the interlocking plant includes the switches about 200 feet south of the bridge where the three track system merges into a two track system; also the switches to a number of industry tracks on both sides of the river whose turnouts are close to the bridge.

The operating mechanism of the bridge is so interlocked with the signal system that it is impossible to unlock or open the bridge when a signal is given for a train, or while a train is within the limits of the interlocking plant. It is also impossible to clear a signal while the bridge is open or unlocked. The interlocking is effected by means of electrically operated locks applied to the controllers of the bridge lock motor and the bridge operating motors, and to the operating shaft of the engine clutches. All operating levers are electrically interlocked to insure proper sequence of operation in manipulating the levers.

The interlocking machine has a capacity of 44 levers. It contains 18 levers for signals, 16 levers for switches and derails, and 3 levers for the special locks between bridge and interlocking apparatus. This leaves 7 unused spaces, reserved for possible future extension of the interlocking plant.

The power for operating the interlocking plant is 110 volt D. C. from storage batteries housed in a building adjacent to the tracks and about 100 feet from the bridge. The batteries are charged by motor-generator sets receiving power from the same source as the bridge motors.

The signals installed are three-position, upper-quadrant type, conforming to the latest established practice on the Chicago & North Western Railway.

Detector bars are installed only at facing points.

The usual channel lights are provided for navigation. These are electrically lighted lamps set on the fenders on either side of channel; also bridge lights at front end of movable span, consisting of lamps with uncolored lenses, suspended in such manner that they hang vertical whatever the position of bridge. In front of each lamp is an arc of red and green glass, the red glass being in front of the lamp when bridge is closed; as the bridge opens, the lamp, swinging about its point of support, passes behind the green section of the arc.

In addition to the lights required by the government, a special wigwag signal for boats was installed on each side of the span, just outside the lower chord and over the middle of the channel. This is a swinging lamp with a red lens, hooded so that the red light is distinctly visible against the dark background, even in bright daylight. The purpose of this signal is to warn approaching boats, by the swinging of the lamps, that bridge cannot be opened immediately, and that they must come to a stop. The lamps are operated by electric motors in the same manner as the swinging signals now much in use at dangerous highway crossings.

The general plan of contruction, and the designs of substructure, approaches, interlocking system, and temporary structures,

were made by the engineering department of the C. & N. W. Ry., under the direction of W. H. Finley, Chief Engineer. The superstructure was designed by the Strauss Bascule Bridge Company, and built by the American Bridge Company. It was erected by the Kelly-Atkinson Construction Company, and the power and operating equipment installed by C. H. Norwood. The substructure and the fenders were constructed by the Great Lakes Dredge & Dock Company. This company also removed the old bridge, both superstructure and substructure, and dredged the new channel. Mr. H. M. Spahr was resident engineer in charge of all field work for the railway company.

DISCUSSION

C. H. Norwood, M. W. S. E.: Due to the comparatively large amount of power required and at infrequent intervals, the Chicago & Northwestern Railway Company decided to purchase the power for their new bridge from the Commonwealth Edison Company. This current is furnished from the Division street substation at 4,000 volts. The service is brought overhead to the railway company's right-of-way and then along same to a point just east and adjacent to the bridge. As an auxiliary source of supply a direct connected gasoline engine is used.

The operating machinery is on the fixed part of the bridge, located in a machinery room above the tracks.

The two operating motors are of 150 H. P. capacity each, 440 V 3 phase, 60 cycle and of the Westinghouse make. Each motor is equipped with a substantial solenoid brake of the General Electric make, adjusted for braking 100% of normal running torque of the motor. These motors are controlled by the Cutler-Hammer magnet type control, consisting of four reversing contactors, and five accelerating contactors for each motor. The master controller for these contactors is mounted on a stand and interlocked with the lock motor in such a way that neither can be operated out of proper sequence. The operations of the lift and lock motors are in turn interlocked with the signal interlocking machine. In opening, all track warning signals must be set to "danger" before motor controllers are released.

All gearing is of cast steel with cut teeth. The clutch for the auxiliary drive is on the first reduction from the engine. The friction plates of the clutch are asbestos composition lined, which has proved most satisfactory where a certain amount of slipping is necessary.

A departure from the usual practice is to be noted in the auxiliary power, a high speed automobile engine being used instead of the slow speed continuous duty engine.

This type of engine has its advantages, in that it is light, well balanced and easily started and regulated. In fact, this outfit is handled as you would handle an automobile. The engine is cranked, the operator moves over to the clutch wheel, where are located the

throttle and spark levers, and when the engine is up to speed, the clutch is gradually thrown in, at the same time more gasoline is allowed to pass into carburetor. The engine used is a four cylinder 4¾″ x 5½″, 45 H. P. Wisconsin Motor Mfg. Co. make operating at 1,100 R. P. M. The governor is adjusted so that a maximum speed of 1,200 R. P. M. can be obtained. On a test of the auxiliary power, the slip gear for the engine was thrown in mesh with main machinery drive, the engine started and the bridge raised to an angle of 45 degrees, all in ten minutes. This type of engine is the first of its kind for this particular service that has come to the writer's attention.

It may be well to note here that the Chicago & Northwestern Railway Company was the first railroad to use the gas engine as motive power on a movable bridge. This was in Milwaukee over the Milwaukee River. The gas was stored in tanks on the bridge. Later this engine was changed over to use gasoline. Since that time stationary gasoline engines became very popular among bridge engineers as a drive for movable bridges.

The service transformers were installed by the Commonwealth Edison Company and consist of three 50 K. V. A. single phase transformers 4000 V to 440 V. From the low tension side of the transformers the current is brought directly to fuses on the switchboard in the operator's house. The max-meters and watt-meters are mounted on the same panel with the main fuses. The distributing panel adjoins the service panel and contains distributing switches, ammeter, voltmeter and indicating wattmeter.

The motor operating the lock on the front end of the bridge consists of a 5 H. P. squirrel cage motor of the high resistance type. Both lock motors and main lifting motors are controlled through limit switches at the ends of their respective travel. The main line contactors for the lifting motors, located on the control panel, are tripped out when the moving span is within 15° of the fully closed position; to close it the remaining distance, a foot switch is provided for releasing the brakes and a push switch for closing the circuit through the contactors, thus short circuiting the limit switch. The motors may then be started by the master controller. In case the line contactors go out, due to overload or short circuits the controller handle must be brought to the neutral position before a new start can be made.

Air at 100 lbs. pressure is supplied to the strut brake and warning whistle. The storage capacity consists of two 25 cu. ft. tanks suspended in the top of operator's house. A General Electric Company's 25 cu. ft. direct connected motor driven air compressor with automatic governor pumps the air to the tanks.

The warning and indicating signals on this bridge are most complete. In addition to the usual channel warning lights required by the government, a wig-wag warning to river traffic has been introduced as a signal to vessels in event of failure of motive power for

the bridge. The wig-wags are located in the center of the bridge on the lower cord and can easily be seen from the river. They are controlled by a snap switch in the controller stand. Directly in front of this stand is a signal box with a lamp and semaphore to each wig-wag motor. The lamp burns and the semaphore goes to "clear" when the wig-wag is operating. In event of failure the semaphore goes to "danger" and the lamp is extinguished.

Under normal balanced conditions, the bridge now requires 450 amperes to start and 250 amperes to operate. The time required for a complete opening is one and one-fourth minutes. This, in the writer's estimation, is too speedy for such a large structure. The vibration is decidedly objectionable. On the other hand, when the bridge is being operated with the gas engine there is no vibration whatever.

O. E. Strehlow, M. W. S. E.: I would like to ask a question about the foundation. I was wondering why the bridge was swung and hinged at the south end instead of the north.

Mr. Dalstrom: One reason was that there was a shorter approach. Also there was a through bridge near the north end.

Mr. Strehlow: Was not the bed rock at the south end at a much lower elevation than at the north end, and if so, did the additional cost of substructure of four cylinders at the south end and only two at the north end, instead of the reverse, constitute a cost of some magnitude?

Mr. Dalstrom: Yes. The substructure at the south end was carried deeper, but the disadvantages from blocking the tracks at the north end, where they spread out to three tracks, and the three track through girder span over the C., M. & St. P. tracks only a short distance away, would have involved difficult and expensive temporary work. The Milwaukee crossing was so close that it would have had to be taken out before the temporary structure could have been installed.

Mr. Strehlow: How much longer would the bridge have been out of commission if it had been a two track instead of a three track bridge?

Mr. Dalstrom: I think there would have been very little difference. We would have had just about the same amount of equipment. There would have been a smaller amount of deck timber to put in, there would have been fewer stringers to place in the south panel, and one less track to put in on the south end of the moving span, after the span was lowered. The difference would probably have been 2 or 3 hours.

James E. Cahill, M. W. S. E.: Can you give us some idea of the ground conditions as compared with the original borings?

Mr. Dalstrom: Only that the ground was reported as being considerably harder than we had anticipated from the terms that were used in describing the material. It was hard enough so that it had to be worked out with picks where it wasn't wet, and it added a little bit to the delay in progress in sinking the cylinders.

L. W. Skov, ASSOC. W. S. E.: I would like to ask Mr. Dalstrom if the initial lining of those cylinders was computed for air space at that time?

Mr. Dalstrom: It was not.

J. W. Lowell, Jr., ASSOC. W. S. E.: Several inquiries have come to my attention where concrete weighing as high as 350 pounds per cubic foot was desired for bridge counterweights. Naturally, the way to obtain such weight is to use extremely heavy aggregates, such as iron or some heavy ore. I would be interested in learning more about how Mr. Dalstrom solved this problem.

Mr. Dalstrom: The aggregate that was used was a heavy stone that is obtained here in Illinois, and a number of test specimens of the concrete were made at the railway company's yards by the contractors. The proportions were varied until they got a density which gave a weight between 170 and 180 lbs. per cu. ft. immediately after they were made. By slightly varying the proportions, they succeeded in getting test specimens with a known proportion, amounting to 160 lbs. and 168 lbs., after 20 days of drying.

Mr. Lowell: How big were the counterweight blocks?

Mr. Dalstrom: They were six inch cubes.

Mr. Lowell: Did they gage the consistency of the concrete in arriving at the density?

Mr. Dalstrom: They recorded the amount of sand, cement, stone and water used, and that would fix the consistency.

Mr. Norwood: I can tell you how the bascule blocks were made on the Great Northern. Their test blocks were one foot. The counterweights were too heavy and they had to put about 15 or 20 tons on the front of the bridge. The engineers came to the conclusion that the concrete dried out in a foot cube, where it did not dry out more than six inches in the main mass of concrete poured into the counterweight box.

I think their point is pretty well taken and I have talked to other engineers on that subject and have practically agreed with them that concrete will not dry out over six inches in mass, and that the water does not get out. If the Great Northern had made its blocks of a cube three feet in diameter, the weights of their test blocks would have been a better guide for determining the weight of their counterweight than they were. This counterweight, as shown in the views, is a very difficult weight to figure and the Great Northern should have gotten closer to it.

D. N. Becker: I wish to know whether those cylinder subpiers were figured as to unit pressure, or just made at 12 feet for construction purposes, in order to get the weight to sink them.

Mr. Dalstrom: Largely for construction purposes, but the unit pressures were figured and they were considerably less than would be necessary with rock foundation.

Mr. Becker: What would you consider as proper on a rock foundation?

Mr. Dalstrom: I think it would be safe to go to 25,000 or 30,000 lbs. per sq. foot on this material.

Mr. Becker: Along that line, I wish to say that in our city bridge work, on our sub-piers, we figure 300 lbs. per square inch on rock. In the Chicago building ordinance, I understand they allow 300 to 400 pounds at the top of the sub-pier, which is even greater. They are running practically 30 tons on rock, which is usual on the buildings around the city.

Mr. Norwood: I would like to draw the attention of those present to a point in the machinery on this job. The last few years engineers have come to the conclusion that it is a good investment to use cut gears and they used cut gears on this job. It costs a little more, but they certainly pay for themselves.

I think the first job on which the city ever used them was on the Chicago Avenue Bridge. It didn't operate very easily and it had not been shown at that time that it gave them any advantage, but some of the later jobs certainly did show the advantage of cut gearing.

In some jobs the expense may amount to several thousand dollars, but the amount of friction done away with, which adds up in the cost of current during the year, makes it certainly worth while to cut the gears.

J. C. Blaylock, M. W. S. E.: I would like to know if the operation of the bridge during the winter, in the sleet and snow, was hindered to any extent, and did the accumulation of ice or sleet and snow affect the operation of the bridge to such an extent that it delayed traffic?

Mr. Dalstrom: We haven't had a very bad winter this year, and the bridge was not really put to the test.

Mr. Norwood: We had a job in Portland, Maine, where it failed, due to the ice and snow on the tracks. The sleet and snow blew in from the ocean—it was a very exposed place—and the rocker got packed up and froze to the track, and it was necessary to break the ice before the bridge could be raised.

Mr. Blaylock: Has there been any trouble due to ice or water freezing in the pit of the counterweights? We generally have that trouble with the bridges where the boxes are below the water level.

Mr. Dalstrom: This pit is not below the water level. It is just a little above the water level.

Mr. Blaylock: What method have you provided for taking care of the water that falls into the pits? Anything whatever?

Mr. Dalstrom: Yes, that drains right into the river. The bottom of the pit is above the level of the water of the river and the pit is open to the north. Any water that falls into the pit can run right out of it into the river.

Mr. Blaylock: Is it an open drain?

Mr. Dalstrom: Yes.

Mr. Becker: In your judgment, was it necessary to place the

steel rails in the tops of the concrete cylinders, or was it done to get rid of old rails?

Mr. Dalstrom: It was not done to get rid of the steel rails, but I do not know that anything would have happened if we had omitted them. They give a greatly increased strength of bond between girder and cylinders, and at a very small cost.

Mr. Norwood: I would like something to be said on the subject of speed of operation.

D. P. Riordan: Why does the city or the government require that speed for the motive power?

Mr. Norwood: To get the river clear as soon as possible. Some of the largest bridges operate in three-quarters of a minute, but if you take a plant like the big bridge of the B. & O. at South Chicago, and try to operate that in too short a time, the power climbs up, and I consider it a very dangerous thing to try to operate these large bridges in such a short time.

E. N. Layfield, M. W. S. E.: I would like to ask Mr. Dalstrom if there is any particular purpose in sealing up those holes in the counterweights, so that the counterweights cannot be changed readily. My experience has been that it is desirable to have some ready means of changing these counterweights. For instance, in the case of one bridge I was concerned with, when we put on heavier ties and heavier rails, it was necessary to change the counterweights. That bridge was nothing like as heavy as the one described by the author, and the percentage of weight of increase was naturally greater than in this case, but it certainly seems desirable to have some ready means of adjusting the counterweights.

Mr. Dalstrom: By sealing them up I did not mean that we closed them up permanently. That sealing consists of only about three-fourths of an inch of cement on a wire netting and any time it is necessary to readjust the counterweight, all that is necessary is to hit it with a hammer and it will come to pieces. The pockets are sealed up more for appearance than anything else.

T. W. Clayton, M. W. S. E.: I would like to ask Mr. Dalstrom the estimated relation of cost of the double leaf bascule.

Mr. Dalstrom: I haven't any figures on that. The double leaf was not applicable to that particular place, and so no comparative figures were made.

Mr. Layfield: I would like to say in response to Mr. Clayton's question that that question received some inquiry in connection with the so-called eight-track bridge over the Drainage Canal near 31st Street and Campbell Avenue. The Sanitary District built this eight-track bridge about 1890, or a little before, for the Pennsylvania Lines, the Chicago Terminal Transfer Railroad and the Chicago Junction Railway. It was a two-leafed bridge, which, from a railroad standpoint, is objectionable on account of the lock in the middle. It was intended to have the machinery installed on each end. Several years elapsed before it was desired to install the machinery, and about 1908, the Sanitary District removed the old bridge and put

in an entirely new one with a single leaf. My understanding was that it was cheaper to do that than it was to install the machinery on both ends of the old bridge, and besides, it was very much better from the standpoint of the railroads.

Mr. Dalstrom stated that the bridge could not be opened after a train had passed the derails. I think it would be interesting if he would explain the operation of the electric track circuits by which this is accomplished.

R. M. Phinney: With a high speed signal cleared for a train, the bridge as well as all derails and switches in the route are locked so that nothing can move until the train has passed over the route and cleared the interlocking plant. If, however, the bridge must be opened or the route changed before the train has accepted the signal, it requires from two to three minutes, two minutes being consumed by a time element release between the setting of the signal in the stop position and the opening of the derail, thus allowing a train which is approaching to stop before reaching the derail. There is no time element release for slow speed signals. With these the derail may be placed on the track immediately after the signal has been put to the stop position. However, when a train is within the signal limits, nothing can be moved except by an emergency switch, which is to be used only when a train is at stop or when a track circuit fails. This switch is in a sealed box.

Mr. Becker: I would like to know whether there was any discussion before the structure was built as to which type of cylinder should be used, whether the steel ring, or wood. It seems to me that the wooden type would have been cheaper than with the steel shell.

Mr. Dalstrom: Steel wasn't as costly as it is now, and there is more certainty of action with a construction like the steel shell. I am not prepared to say that it would have been practical to have carried down the wooden one. We would have had to change our procedure considerably from the manner in which we did work and we weren't sure at first that we would not have to resort to air pressure, and we were prepared for it with what we had made.

Mr. Cahill: Supplementing Mr. Dalstrom's remarks on steel cylinders being designed for use on this work, we believe that this design was due in main to a sort of tradition handed down among the outside or field men that a slough or swamp existed in the early days at the site of this bridge and that this slough had been filled in by the railroad company in placing their embankment. In view of this condition, the men believed that it would be necessary to use compressed air and water tight steel cylinders to get down to rock without any danger of trouble from bad material.

John B. Johnson: How much variation did you allow on the cylinders?

Mr. Dalstrom: Variation from the center of the lines fixed, do you mean?

Mr. Johnson: Yes.

Mr. Dalstrom: I don't believe I can give you the exact figures, but it did not exceed six inches, which in that case was immaterial, because the concrete cross-beams were of such size that they could be displaced that much from the center without affecting the stability in any way.

In the last case of cylinder construction we had, which was on the Illinois River at Peoria, the cylinders were carried down somewhat deeper below the ground line, and considerably deeper below the water level—but greater precautions were taken to keep them in their places, and I think the greatest displacement there was three inches. The height of the cylinders from the top to the bottom was about ninety feet, but only about fifty feet was in the earth. About fifteen feet was in the water and the rest of the cylinder above water.

Mr. Norwood: Did you use any special steel on that bridge?

Mr. Dalstrom: No.

THE PREPARATION OF ROCK PRODUCTS

*By Raymond W. Dull, M. W. S. E.**

Presented March 5, 1917.

Sand and gravel or crushed rock plants just a few years ago consisted of a combination of individual ideas, local practice, market requirements, theories, some engineering, common sense and errors.

Local practice in many localities was satisfied with the use the bank run or crusher varieties of concrete materials, with no particular care taken regarding percentages of voids, graduations or foreign matter. I would estimate that at the present time fully half of the gravel pits operating market their gravel just as it runs from the bank, all combined together from 1½" stone to ¼" pebbles, some of it washed, but without any regard to the amount of each size, just so it is gravel with the sand taken out.

We will endeavor to give our views regarding proper methods to use in the preparation of these rock products, with particular reference to washing and sizing.

It has been demonstrated that materials assembled together in such proportions as to form the densest mass make the cheapest and strongest concrete. This, then, calls for the producer to grade his gravel into several sizes. The materials can then be re-combined to approximate the densest mass. Since the dollar and cents argument is usually the most impressive, we wish to give Taylor and Thompson as an authority on mixtures with different percentages of voids, to show the folly of using the 1½" to ¼" gravel as it comes from the bank or river, even if it is washed. Materials handled in this manner will vary from 30 per cent to 50 per cent of voids.

Assuming a mixture of 1 -2½ -5, an approximate delivered cost per bbl. of cement of $1.70, sand at $1.00 and stone of $1.70 per yard, the total cost for material to make one cubic yard of concrete with stone or gravel having 50 per cent voids is $4.34; with 40 per cent voids $4.02 and with 30 per cent voids $3.68, a saving surely worth consideration.

Assuming then that it is desirable to grade the stone or gravel into several different sizes to recombine into the densest mass, we will discuss the best practice to make this separation. The general practice in coal screening and in fact all dry screening processes is to take out the fine materials first. This method retards the screening efficiency because the large pieces of material cover to a great degree the openings in the screen and hinder the smaller particles from passing through. With the use of water and individual screens it is possible to take out the largest particles first.

Greater screening efficiency is obtained in this manner because when the first separation is made we have the greatest quantity to

*President Raymond W. Dull Co., Chicago.

screen and with the large size holes the material will more readily pass through the large holes than through the small holes and when we have screened down to the smaller sizes, which are more difficult to screen, we have to screen only a small percentage of the material we had at the start of the process.

We also find with this latter system that the finer screens, which are more delicate, are not subject to as much wear since they are relieved of the large stone.

By using individual screens for making each separate size, a trough or flume usually carries the material, which passes through each screen, by the aid of the washing water, into the following screen. The water is then used over and over again as each size of material is taken out, which utilizes the water to the fullest advantage.

The correct principle of washing materials is to agitate the material and water sufficiently to get all the mud and other impurities into suspension in the water. If any free mud is left and is not in suspension the washing has not been thoroughly done and the materials will not be clean.

A few years ago the writer was confronted with the problem of designing gravel washing equipment and undertook to develop machinery best suited for the purpose. Engineers had given the matter very little attention and the gravel pit owners were either compelled to develop their own machinery or to use equipment on the market very poorly adapted for the purpose. Shaker screens designed for coal screening or cylinder screens made for stone crushing were used principally.

Our final development of screens was the Inclined Conical Screens, all mounted on an inclined shaft. Our reason for designing the screens in this manner was to simplify the driving machinery for the individual screen arrangement. To install separate driving mechanism with the consequent wear was the first thing to avoid. The second condition was to give the inclination of the screening surface the best working angle and the third condition to give the water pans for fluming from screen to screen the minimum possible slope and still carry the solids by the washing water. The last condition was necessary to keep the height of plant as low as possible and cheapen the cost of raising the material to the top of the plant.

Figure 1 shows the result. This set of screens has the simple drive. Only a pair of gears and a counter shaft constitute the drive connections for all the screens. The lower portion of the screens has the best screening inclination, which is 1½" per foot. The water pans have a minimum slope of 2½ in. per ft. So we have the three fundamental conditions all fulfilled in a remarkably simple manner. The bulk of the water is introduced at the large end of the first screen, which takes out the coarsest material, which passes out the small end of the screen.

The material which passes through the screen is carried by the

water in the water-pan below the screen into the second screen when a second size somewhat smaller than the first size is taken out by the second screen in the same manner as the first size is obtained. This process is continued through the series of screen until all the gravel is removed. We now have remaining the muddy water and scoured sand which we will separate by the sand separator.

SCRUBBING

Many materials do not always readily become clean without preliminary scrubbing. We found it advisable to devise something

Fig. 1. Two Rows of Inclined Conical Screens, Showing Flumes to Sand Separators.

to agitate the materials and scour the stone to a considerable extent before going into the washing screens.

The scrubber consists of a large cylinder mounted on the extension of the screen shaft axis and driven by the same gears. The cylinder is divided by internal rings which retain the material and water in the compartments and the lifting vanes agitate and scour the mass similar to the action of a concrete mixer. The mass overflows from one compartment to the next and after passing through the four stages, the preliminary work is accomplished.

In addition to the water first introduced we arrange several

jets, at the small ends of each screen, which flow in opposite direction to the travel of the material. These jets wash off this muddy water, sand and other particles which cling to the stone.

SAND SEPARATORS

We will now take up the separation of the sand from the muddy water. The most of the power operated devices for this work which were in use for this work would not last very long. We made some extensive experiments to determine the best method of extraction of the sand. If the sand and water were run off together the water would soak through the sand and leave the mud in the sand similar to a filter bed. By inverting this method and drawing off the water at the top and with it the impurities held in suspension, and the sand below, we were able to obtain the desired results.

Our experiments determined that a conical shaped tank suspended on scale beam levers was the most efficient device. The scale beam levers have knife edges and are almost as sensitive as any scale. The cone valve at the lower point of the tank is connected with the counter-weight lever and an upward motion of the counter weight lowers the cone valve. If, then, sufficient sand accummulates or settles in the tank to cause the counter weight to rise, the cone valve drops and a sufficient amount of sand escapes from the tank to the bins below until the tank is relieved of the excess weight and the valve is automatically closed. The discharge is intermittent and there is a sufficient quantity of sand in the tank at all times to make a sand seal to prevent the water from going through with the sand.

BIN CONSTRUCTION

In some of the earlier plants which we designed used the cribbed construction. We found that the life of the bins was short because the water would be held in the cracks between the planks and the wood would decay rapidly.

We then adopted a construction which did not have this fault, was more accessible for the replacement of timbers and provided means to perpetuate the life of the bins.

You will note that vertical studding is used with planking spiked on the inside and whallens on the outside of the studding to reinforce them. Heavy steel tie rods with large washers run through the whallens from wall to wall take care of the side pressures of the bin walls. The spacing of the studding and whallens are closer together at the bottom of the bin and farther apart near the top, where the pressure is not so great, and in this way a minimum amount of lumber is used for the bins.

You will also note that no floors are used in the bins. The material is put in the various bins and only the material above the flow angle of the gates is drawn off. The material below the gates forms the floor with the hopper effect leading to each gate. The bed of material also forms means for the escape of the water cling-

ing to the material after washing and the material is loaded into the cars in a dryer state.

A few bins are made of reinforced concrete but this is not a very general practice. The reason is the increased cost and no great necessity for permanence.

We have also installed plants with circular steel tanks but not since the price of steel has advanced to make this construction prohibitive.

METHODS USED FOR EXCAVATING MATERIALS

Quite a variety of methods are used for excavating the material. One reason is that pit owners are often contractors who have purchased steam shovels or locomotive cranes and wish to use them rather than buy special equipment. The physical condition also is a great deciding factor on the best method for excavating and another deciding factor is the capacity of the plant.

Fig. 2. Plant of the Akron Sand and Gravel Company, Akron, O., Showing Hopper, Crusher House and Conveyor Leading to Top of Plant. Crib Bins Are Reinforced With Railroad Iron.

In some localities the material is taken from a river and calls for a cableway of 1,000 or even 1,500 ft. span. Some of these cableways have travelling towers and others pivot about one tower and have the other tower mounted on circular tracks. River work is more or less hazardous due to floods, and unless a floating plant is installed the cableway system is used with towers which are placed on opposite banks.

Another system of excavation which has become very popular where local conditions will permit, is the slack line cableway excavator. These systems will operate very efficiently over a span of 500 ft. but we do not recommend them for a greater span. This system operates much faster than the other style of cable way.

This style of excavator is installed with a main tower or mast

at one end and an anchorage of some sort at the ground level at the other end. The bucket is suspended from a trolley which runs on the main track line. The machine is operated by a two drum hoist. The main cable is raised and lowered by means of a block and fall arrangement, the cable from which leads to one of the drums of the hoist. Another cable called the load or drag line is attached to the bucket and leads to the other drum on the hoist.

In operating the bucket runs down the inclined main track line by releasing the clutch on the drum and controlling the drum by the brake. The descent of the bucket is very rapid, and it only requires about ten seconds to travel the 500 ft. When the bucket reaches the digging point the main track line is lowered until the bucket rests on the material. The bucket is loaded by pulling forward and when full the main track line is raised and the bucket is brought to the dumping point.

A few cars are designed to take the cars which bring the material from the steam shovel up an inclined trestle by means of a hoist. This method is satisfactory for small plants but is hardly as efficient as the belt conveyors on larger plants.

BELT CONVEYOR SYSTEMS

The usual arrangement for belt conveyors is from a track hopper into which cars dump and from the hopper the material is fed to the belt conveyor which carries it to the top of the plant. The commercial cast iron idler is not very strong and we have developed an idler with a pressed steel pulley for this work.

FIELD-CONVEYORS

Another method used for bringing the material from the excavator to the plant is the field conveyor. The way we advocate constructing them is to build the conveyor on a series of sleds. Each sled can then be lined up independently. The advantage of this system is that a continuous flow of material goes to the plant. Better screening results on account of this steady flow through the screens.

POWER USED

Most of the plants are electrically operated with small groups of driving connections for the smaller machines and individual drives for the larger units. Steam-driven plants are also extensively used and a few use oil engines.

The oil engine plants which are near the source of oil supply are able to furnish power cheaper than any other kind of power.

FLOATING PLANTS

In dredging from the river many plants are constructed on boats. A complete washing plant for washing and grading and making a finished product delivers to several scows alongside the

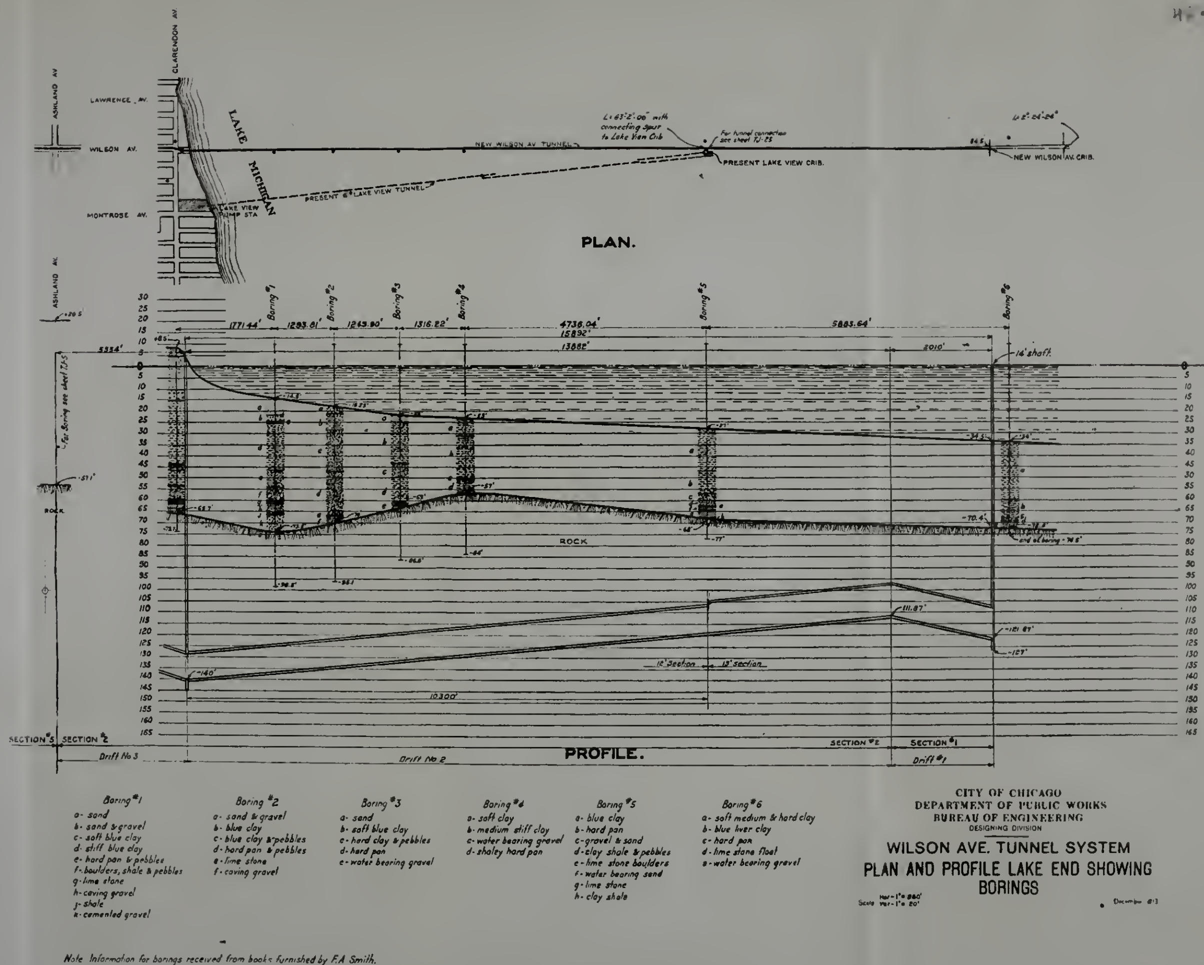

Fig. 1. Plan and Profile of Lake End of Wilson Avenue Tunnel System.

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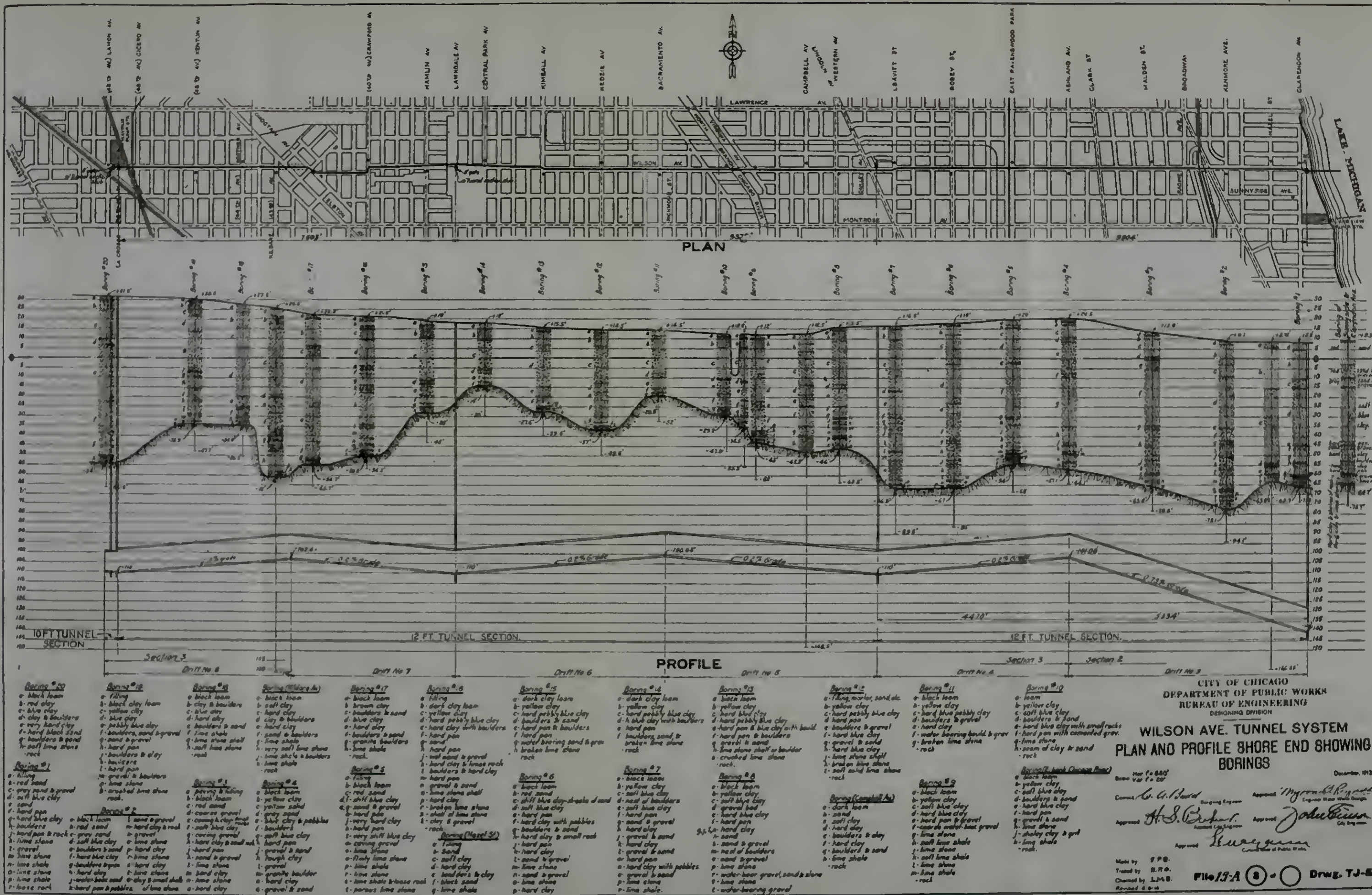

Fig. 2. Plan and Profile of Shore End of Wilson Avenue Tunnel System.

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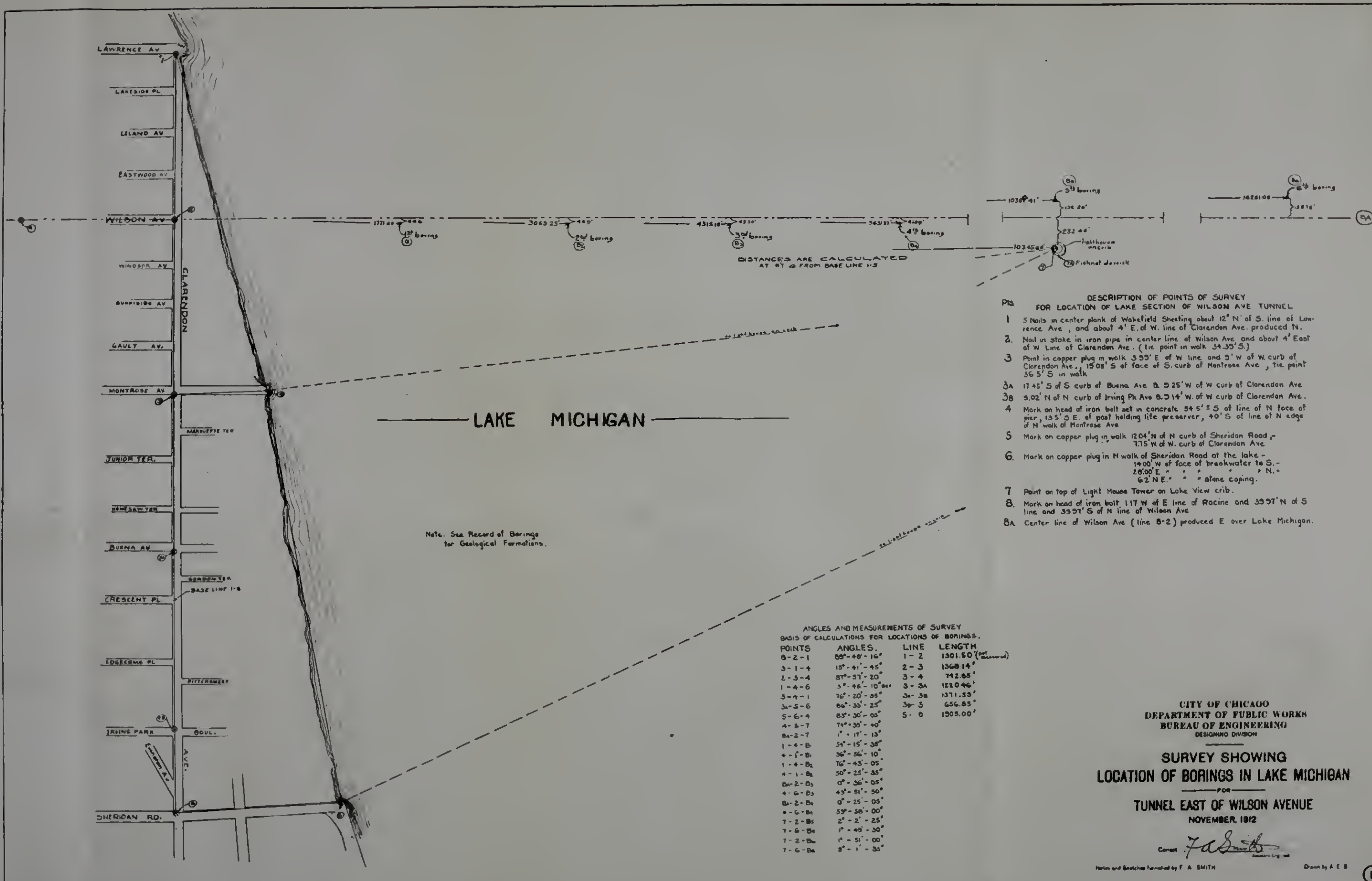

Fig. 3. Survey Showing Borings in Lake Michigan, Wilson Avenue Tunnel System.

boat. Each scow receives a different grade and the waste material is run back into the river or lake.

These plants must also be designed to suit many different conditions. In some cases dredge pumps are used and where the material is too hard for pumping orange-peel buckets are used. Dredging elevators are also used for this purpose.

DREDGE OPERATION DELIVERING TO LAND PLANT

This style of plant, where a portion of the material to be excavated is below water level and is not packed too tight, gives very efficient results. Many installations have gone wrong because they have attempted to pump to the top of the plant, which resulted in excessive power requirements and numerous mechanical and screening difficulties. We recommend pumping to the plant with the pipe line as near horizontal as possible. The material can be dewatered in a concrete sump or basin and the material elevated to the top of the plant by a dredging elevator. Take as an example, a dredge pump usually delivers 10 per cent solids, and to raise ten tons of water to get one ton of material is not a very efficient process.

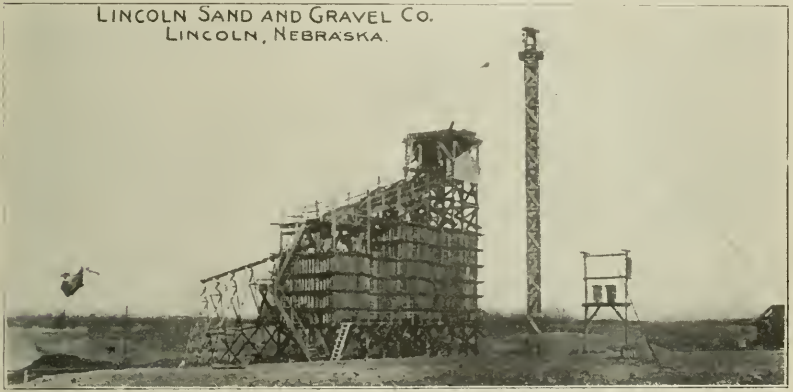

Fig. 3. A Cableway Excavator with 600 Foot Span. Bucket is Digger, Elevator and Conveyor in One.

The dredging elevator is fitted with manganese and chrome nickel wearing parts and dredges out the bottom of the sump in a continuous operation without much attention.

DISCUSSION

The Chairman, W. W. De Berard: This most interesting paper is now open for discussion. I would like to know the maximum angle at which the belt conveyor will work efficiently.

Mr. Dull: It varies with the kind of material you are carrying. With crushed stone or gravel it is 18 or 19 degrees, and with a mixture of sand and gravel it is as high as 22 degrees.

Mr. De Berard: Can they mix that material sufficiently close

to use it directly and simply add the cement to it, and make it into concrete, or is that for some other purpose?

Mr. Dull: The Huron Gravel Company are mixing it with cement without any addition or correction.

Mr. De Berard: I think that is extremely interesting because that is one of the things that the engineers do not always pay enough attention to. They get a call for a 1-2-4 mix when it ought to be 1-2 and 3/8, or something like that.

Mr. Artingstall, M. W. S. E.: I remember a picture which showed a steel mast. The question arose in my mind as to what sort of connection there was between the foundation and the foot of the mast. That is, whether you had a pin connection or whether it was rigid?

Mr. Dull: We have a swivel connection which is a sort of ball and socket. The distance from tower to anchorage is about 800 ft. and so it is not necessary to move it very often. We are taking the material out of the river where it rises and falls every season.

Mr. J. W. Lowell, Jr., M. W. S. E.: I was very much interested in Mr. Dull's paper, and there are a few questions I would like to ask. What is the gauge of the metal you use in the screens; what amount of water is generally required for washing the gravel, and what is the character and size of pumps used?

Mr. Dull: The larger perforations are made from about 1/4 in. or 5/16 in, metal and in some cases, 3/8 in. In the smaller perforations 1/4 in. holes, for instance, it is about 14 gauge metal. It is not practical to use a very thick metal with small holes, even if it were mechanically possible, on account of the plugging up of the holes.

A centrifugal pump is used, provided the conditions are all right. In some cases it is necessary to put down deep well pumps, and then a deep well turbine or a long stroke plunger pump is used.

The amount of water depends on how dirty the material is. With a greater percentage of mud and clay it requires considerably more water, and it is simply a case of judging from experience whether or not anything unusual is necessary. It varies from two to six volumes. Usually one cubic foot of material requires two cubic feet of water.

Mr. Lowell: What is the depreciation on such a plant as this, and how long will the screens last? How many tons of material, or yards of pit material can be handled before they have to be replaced?

Mr. Dull: There is a variety of data on the wear of screen plates. In fact, it has been graduated by the kind of steel we are getting. The screens now-a-days are made out of almost anything the perforators can get. We suspect at times that some of it is made out of old rails and everything else, and it is very soft and naturally wears out very quickly. I think, in the first place, the thing is to get a good grade of high carbon steel plate. I think the perforated plate with 40 per cent carbon will give you the maximum

wear, and the life of the plate is governed by that more than anything else. I don't know that I have any data in tons. The plates would last from two to three seasons.

Mr. Lowell: During the last two construction seasons there has been a great deal of activity all winter in concrete work, and we believe that the contractors are coming more and more to recognize the advantage of concreting in the winter time, and it will only be a few years until the contractors will be glad to get all the work they can. During the past season and the past winter a great many said they were not able to get materials as the screening plants had closed down during the winter. Have you taken up that problem, of producing during the winter?

Mr. Dull: The problem of washing during the winter time is quite a difficult one. The material will freeze in the screens, it will freeze in the bins and in the cars. For these reasons we are working on the storage system, to prepare the material in the summer months and not try to wash it during the winter months.

Mr. Lowell: Is there any standard of perforation?

Mr. Dull: There really is no standard on perforation. It is a matter that I have been trying to get at for three years, and to have the producers' association standardize. I told them it would be possible for us to carry equipment in stock and manufacture it much cheaper, and that it would simplify the matter considerably. One locality will call for roofing gravel made through a ¾-in. hole and over ½ in. and another locality will call for ½ in. and over ¼ in., and some will call for anything that goes through a ⅜ in. screen—they call that sand, and it requires a study of each locality to determine what to recommend for the plant.

Mr. De Berard: A long time ago, 15 years ago, I had a lot to do with sand separation in the way of making a filtration sand. We always used a jet at the bottom to throw the sand from one separator to another and used five or six, and would put an additional separator in the bottom, or we would put a ring around the base of the separator and flood an additional amount of water there to flow over the lip. Now, it strikes me that if you had an additional amount of water in there, and it came up through that, you probably could wash out more material than you do now. That is in case everything was not actually in suspension.

Mr. Dull: We have done that, especially where we wanted to wash out the fine floury sand, which does not make very good concrete.

Mr. De Berard: Filtration people find that after they have used these machines for two, three or five years, that all that fine floury sand and fine other material is lost, and the material that would go through a 60 or 80 mesh seive was lost to them and their sand pits were gradually becoming larger sized sand and they returned this material to the sand pit. They find that the material, if they didn't take it all out would be coarse on top and fine in the bottom, and that they would have strata on the bottom that would give

them a great deal of trouble, and it came about through this use of the upward jet.

Mr. B. E. Ahlskog, M. W. S. E.: I would like to have Mr. Dull explain as to the water jets; the direction through which the water is forced.

Mr. Dull: The jets are placed on the screens at the discharge end and they play on the gravel in the direction opposite to the travel of the gravel. It is necessary, sometimes, to install two or three of these jets, and distribute them along the length of the screens so that you give the gravel a good rinsing while it is traveling on the screens. The way we usually make those jets is to put a cap over the end of the pipe, and then saw a slot in the pipe, making a fan shaped jet.

Mr. Wm. Artingstall, M. W. S. E.: Other than simplifying the

Fig. 4. Dredge Pump Mounted on Scow in Small Pond, Discharging Sand and Gravel Into Concrete Sump. Bucket Elevator Lifts Material to Screens Over the Bins.

driving method, are there advantages in having the screens all on one shaft as is shown?

Mr. Dull: We like the system of using the large end of the screen for the work rather than the small end and it works out by mounting the screens on the shaft that way. Most of the material goes through the first one-third of the screens, and the other two-thirds catches the balance, and if we can make the large end of the screen do that work, we have more perforations and more wearing surface and that makes the screen last more uniformly from one end to the other.

Mr. Artingstall: Mr. Dull has spoken of the last end of the gravel pits—the gravel business—practically the last end. I have had the last end, I think, and the first end. The last end in using material, and I think, while Mr. Dull says that they can mix the

gravel and get a theoretically proper mix, it is not very satisfactory to the engineer, if he has a fairly good inspector on the job, because that fine stuff is bound to get down into the bottom of the car and when you come to use that material on the job, you have to re-mix it, and then you will have a fight with the contractor and when you get into a fight with the contractor, you usually get the worst of it.

Mr. Dull brought out the proposition, as I understand it; you wash your material by turning the water in with the flow of the material.

Mr. Dull: It goes in the opposite direction.

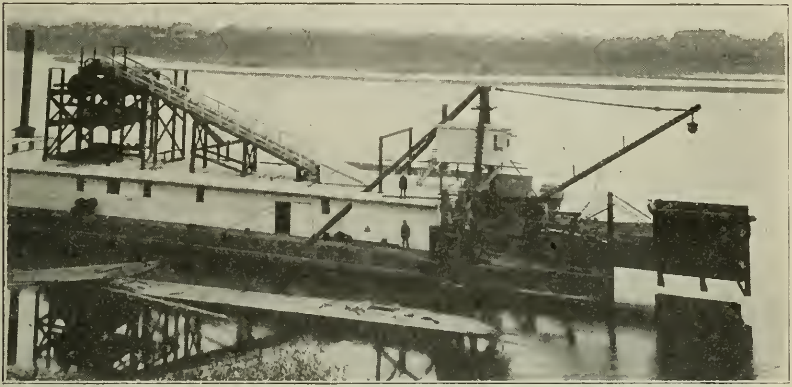

Fig. 5. A River Plant Complete Excavating with Clam-shell Bucket Into Hopper, from Which the Material is Carried by Elevators to Screens. Discharge Is Into Scows Alongside.

Mr. Artingstall: I misunderstood you then. I thought it was the other way.

Mr. Dull: That is the rinsing water. That goes in the opposite direction to the flow of the material, but the main bulk of the washing water goes with the material, usually.

Mr. Artingstall: I thought that by working the water against the material you could get a better cleaning and with less water.

Mr. Dull: By using the jet, as the material is in the screen, you use the water, bringing it back into each screen, and if you have agitated it enough to get all the mud in suspension in the water, you will get the material clean.

Mr. Artingstall: I have made some experiments in that line and I think the greatest amount of water that I ever figured on using in getting absolutely clean material, was about 235 gallons of water to the yard. That was pretty dirty material, and was running somewhere about 65 per cent sand.

Mr. Dull: I think possibly some clay was in it. With only loam, it is easy to wash.

Mr. De Berard: It strikes me that the amount of water you are using is pretty high. In the experiments we made in filtration work, the amount of water, as I recall it, could have been reduced to 35 per cent.

Mr. Dull: I am a great believer in plenty of water. It is pretty cheap.

Mr. H. S. Shimizu, M. W. S. E.: Is there any objection to shaking screens?

Mr. Dull: They shake themselves to pieces. They tear themselves to pieces quickly, and then, on the larger sizes, the stone will drop into the holes, and a great amount of shaking will not shake them out. It is necessary to have knockers underneath to pound them out and that is pretty hard on the screen.

Fig. 6. A Pumping Dredge. Discharge from Pump Is Into De-watering Grizzly Feeding Direct Into Screens. Loading Is Into Scows Alongside.

Mr. Shimizu: Did you ever try a square perforation?

Mr. Dull: Yes.

Mr. Shimizu: Do you not think it is better than the round ones?

Mr. Dull: No, we prefer the round ones.

Mr. Shimizu: Why is that?

Mr. Dull: Well, the stones do not seem to plug them up so much as with the others.

SURVEY METHODS USED ON THE WILSON AVENUE TUNNEL, CHICAGO, ILL.

*H. W. Clausen, M. W. S. E.**

Presented May 21 1917.

LINE OF WILSON AVENUE

Wilson avenue, for the distance traversed by the tunnel, though practically straight, has several offsets and a few very small angles and is not actually a straight line. It also varies in width from 80 to 66 ft. Between Crawford ave. and Kildare ave., the streets run diagonally parallel to Elston ave., and there is no direct connection of Wilson ave. between these points. It continues westerly from Kildare ave.

A short distance south of Wilson ave., at Crawford ave., there is a 50 ft. street which runs from Crawford ave. westerly a short distance. This street was formerly named Miller st., but is now called Wilson ave. This was not considered a part of Wilson ave. when preliminary surveys were made, although it was considered as part of the tunnel line.

Following the center line of Wilson ave. westerly from Clarendon ave., there is an angle at Racine ave. where the line bears 00°03′00″ south, and at Ashland ave. it bears 00°00′45″ north. At Leavitt st. there is an offset of 30.35 ft. to the south, and at Western ave. there is another offset of 5.65 ft. to the south. At Kimball ave., the street continues westerly on an offset of 38.85 ft. north. At Crawford ave., the renamed portion of Wilson ave. continues westerly on a line which is offset 182.00 ft. to the south. That part of Wilson ave. west of Kildare ave. is on the same line with the part from Crawford ave. to Kimball ave.

PRELIMINARY SURVEY FOR LAND PORTION OF TUNNEL

A preliminary survey was made along Wilson ave. from Clarendon ave. to N. Lamon ave., to determine the possibility of driving a 12 ft. tunnel which would remain within the street lines of Wilson ave.

The 12 ft. tunnel section called for 13 ft. 4 in. excavation, and it was desired to pass under the offsets in the street without having to resort to sharp curves and short tangents.

The preliminary survey included a preliminary tunnel line coinciding as far as possible with the center line of Wilson ave. This line was run from Clarendon ave. to Crawford ave. and from Elston ave. to N. Lamon ave. At Crawford ave. and at Elston ave. this line was connected to a closed survey of the intervening

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section between Crawford and Elston aves. This preliminary tunnel line showed that it was possible to pass under Wilson ave. at the offsets, using long tangents and still remain within the street lines. The preliminary tunnel line was started at a point on the center line of Wilson ave. four feet east of the west line of Clarendon ave., and was run on the center line of Wilson ave. westerly to a point 1.17 ft. east of the east line of Racine ave. The line was continued west from this point, bearing 00°03′00″ south, to a point 1.8 ft. west of the east line of Ashland ave. Continuing west from this point, the line remained on the center line of Wilson ave., bearing 00°00′45″ north, to a point 1.73 ft. east of west line of Robey st. The next portion of the preliminary line ran from this point to

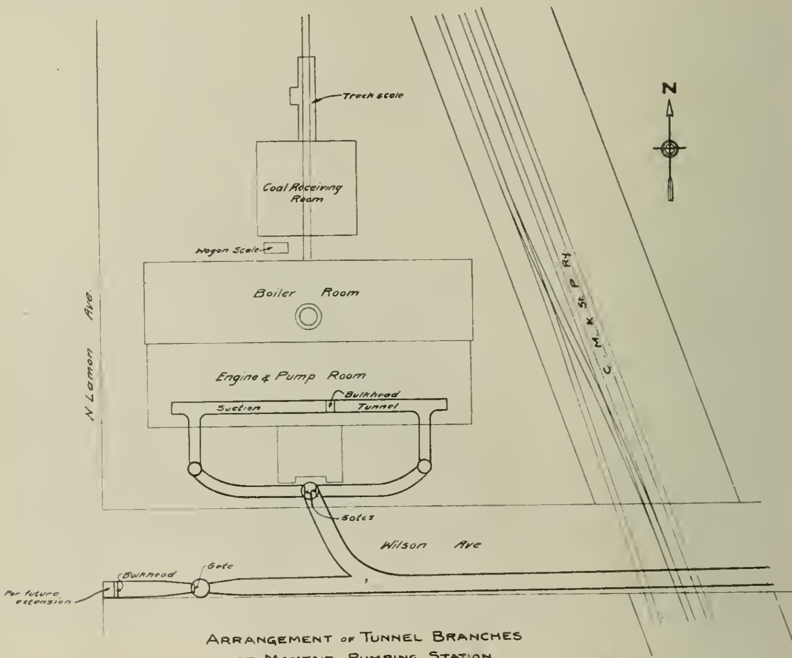

Fig. 4. Connections of Tunnel at Mayfair Pumping Station, Wilson Avenue Tunnel System.

a point on the center line of Wilson ave. 0.60 ft. east of the west line of Western ave. This portion of the line passed both the offsets at Leavitt st. and Western ave., bearing 00°49′00″ south of the previous portion. The next portion of the line ran from the point at Western ave. to a point on the center line of Wilson ave. 0.95 ft. west of west line of Kedzie ave. This line bears 1°18′25″ north of the previous section. Between the points at Western ave. and Kedzie ave. two intermediate points were set on the line.

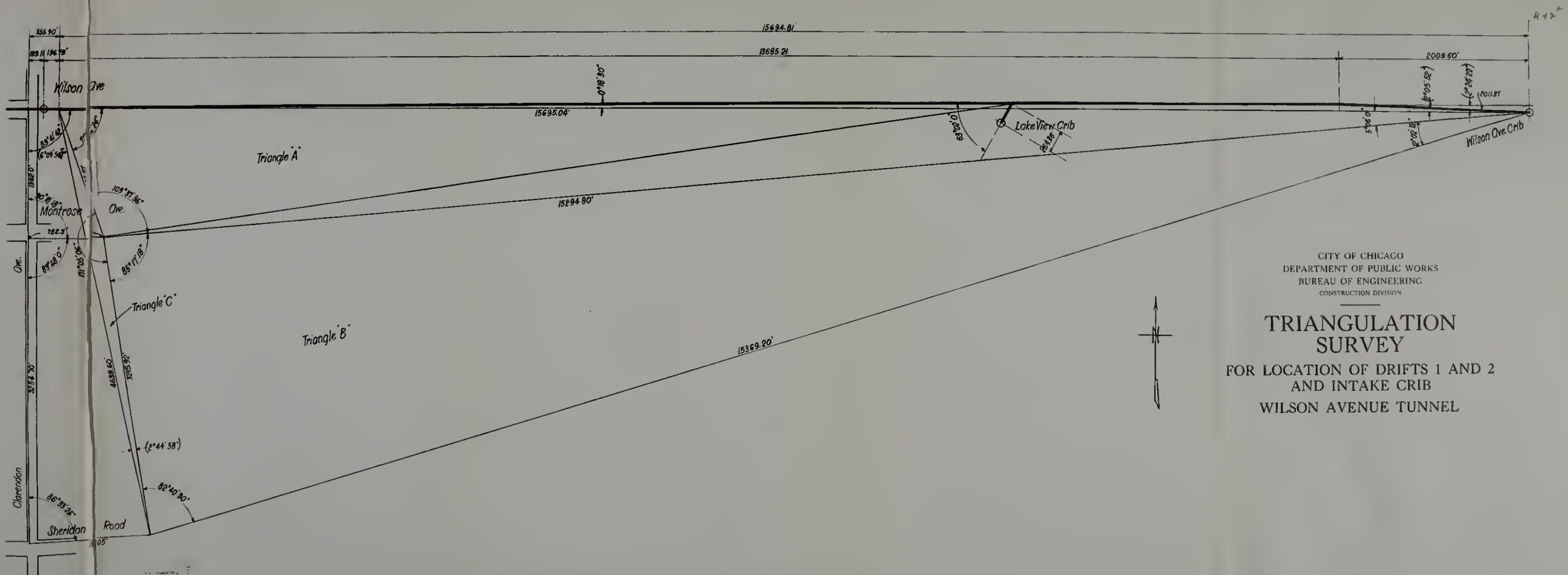

Fig. 5. Triangulation Survey for Location of Drifts 1 and 2, and Intake Crib, Wilson Avenue Tunnel System.

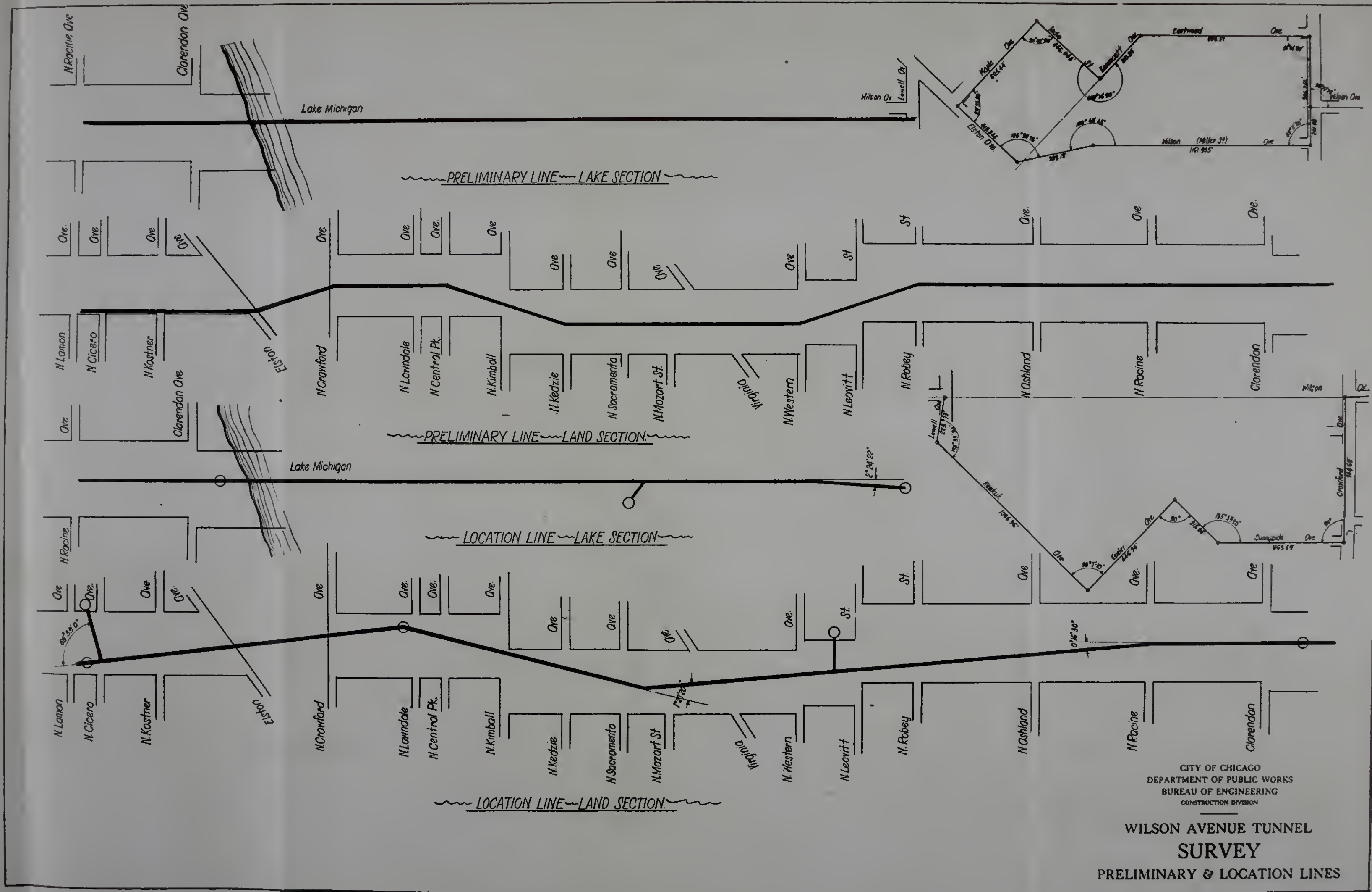

Fig. 6. Preliminary and Location Lines, Wilson Avenue Tunnel System.

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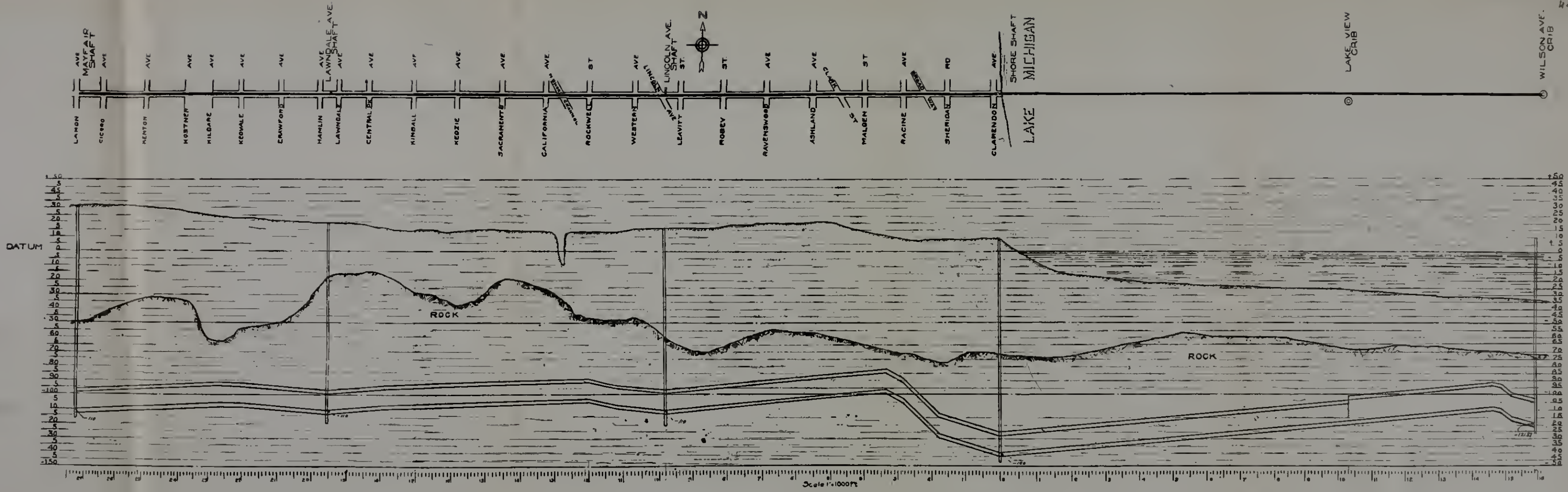

PROGRESS MAP

WILSON AVENUE TUNNEL

Fig. 9. Progress Map, Wilson Avenue Tunnel System.

From Kedzie ave., the preliminary line was continued westerly, bearing 00°29′55″ north, to a point on the southeast corner of Kimball ave. and Wilson ave., and from this point, bearing 00°23′25″ north, to a point at the intersection of the center line of Wilson ave. and Central Park ave. From this point the line was continued west on the center line of Wilson ave. to a point on the west side of Crawford ave. 1.24 ft. west of east edge of walk. Here the preliminary line was connected to the closed survey of the intervening district between this point and the point on Elston ave. where the preliminary line was resumed and run westerly to N. Lamon ave. on a line parallel to Wilson ave. and 2 ft. north of the south line.

The district between Crawford ave. and Elston ave. was surveyed for the purpose of connecting the two points on the preliminary line between which no direct line could be run on the surface. The district was enclosed by a line running north 364.27 ft., on Crawford ave. to Eastwood ave. westerly 888.57 ft., on Eastwood ave. to Selwyn ave. 310.24 ft., on Selwyn ave. southwesterly to India st. 446.05 ft., northwesterly on India st. to Maple ave. 605.44 ft., southwesterly on Maple ave. to Elston ave. 419.35 ft., southeasterly on Elston ave. to a point near Selwyn ave. and from this point 398.19 ft. northeasterly to a point on Miller and Choctaw aves., thence 1,161.94 ft. easterly on Miller ave. to Crawford ave., and 201.98 ft. north on Crawford ave. to the same point on the preliminary line where the survey started.

PRELIMINARY TRIANGULATION SURVEY FOR LOCATING BUOYS FOR BORINGS AND CRIB (LAKE PORTION)

A triangulation survey was made for the purpose of locating buoys for the lake borings and for placing the crib. The base line for this triangulation was established on the west side of Clarendon ave and was run parrallel to and four feet east of the west line of Clarendon ave. This base line was run from a point on the center line of Wilson ave. to a point on the northwest corner of Sheridan road and Clarendon ave. This base line was 4,616.98 ft. long, and was tied in to a point on Montrose ave. at Lake Michigan and a point on Sheridan road at Lake Michigan. From the points on Wilson ave., Montrose ave. and Lake Michigan, Sheridan road and Lake Michigan, the buoys for the borings and crib were set.

The boring buoys were then set by sighting from the point on Wilson ave. along the center line of Wilson ave. extending east over Lake Michigan and from the point on Sheridan road and Lake Michigan by sighting on Lake View Crib and turning the computed angle to the boring. After the buoys were set, the boring platforms were erected on piles and the boring made. These borings were made a short distance north and south of the center line of Wilson ave. extended east over Lake Michigan.

Later the buoy for placing the crib was placed. This was done by sighting from a point on the center line of the Wilson Avenue

Tunnel extended east over Lake Michigan and from the point on Sheridan road and Lake Michigan. Four reference buoys were placed near the crib buoy.

LOCATION OF SHAFTS

After the site for the pumping station had been selected and the total length of the tunnel on land thus determined, selections of locations for shafts were made with consideration for their available vacant space to serve for storage for the rock excavated in the tunnel. Selection was made also with regard to future connections to the tunnel as all the land shafts are gate shafts constructed for 8 ft. tunnel connections. It was also desirable to have the shafts located so as to make the drifts fairly uniform in length. The total length of the land section is five miles. The Lincoln ave. shaft is located approximately 1⅞ miles west of the Shore shaft. The Lawndale ave. shaft is located approximately 1¾ miles from the Lincoln ave. shaft, and the Mayfair shaft is approximately 1½ miles from the Lawndale ave. shaft. The shafts west of the Shore shaft were located off the center line of Wilson ave., so that traffic would not be impeded by blocking the street or closing it entirely. The Wilson ave. Shore shaft is located on the center line of Wilson ave. 75 ft. east of the east line of Clarendon ave. This is on the shore of Lake Michigan at the street end. The Lincoln ave. shaft is located on the center line of the alley east of Lincoln ave. and at a point 81.5 ft. north of the north line of Wilson ave. The Lawndale ave. shaft is located 125 ft. west of the west line of Lawndale ave. and 8 ft. south of the north line of Wilson ave. The shaft is located eccentrically on the tunnel 1 foot south, so that the tunnel line is 9 ft. south of the north line of Wilson ave.

There are two shafts at Mayfair, one being the shaft for the pumping station supply, and the other being a gate shaft for a future extension. The first was the working shaft for the tunnel, and is located on the pumping station grounds 153.5 ft. east of the east line of N. Lamon ave. and 12 ft. north of the north line of Wilson ave. The second shaft is located 72 ft. east of the east line of N. Lamon ave. and 8 ft. north of the south line of Wilson ave. There are also two screen shafts connected to the main station shaft. These were not sunk to rock. They are located on the station grounds 18 ft. north of the main shaft and 85 ft. on each side of it.

TRIANGULATION SURVEY FOR MEASURING EXACT LOCATION OF CRIB AND FOR CONNECTION DRIFTS NOS. 1 AND 2

After the crib shell had been placed in position a triangulation survey was made to determine its exact location and distance from the Shore shaft.

On account of the fact that some of the points of the triangulation survey used for setting the buoys for borings and crib had been removed by the laying of new pavements and building operations, it

was necessary to make a new triangulation, using, as far as possible, the points still available from the old. The tunnel having now been excavated some 9,000 ft., it was decided to use points in Wilson ave. on the tunnel line. These points were located on the pile bulkhead at the end of Wilson ave. 196.79 ft. east of the Shore shaft and in the pavement 139.11 ft. west of the Shore shaft. From this latter point a base-line was run south 1,362.0 ft., making an angle with tunnel line of 89°41′42″, to the southwest corner of Montrose ave. and Clarendon ave. An angle of 90°18′18″ was turned to the east, and a new point established in the lake shore at Montrose ave. 782.50 ft. east, this line being parallel to the line of the Wilson avenue tunnel. Knowing from measured distances the lengths of these lines in Clarendon ave. between Wilson ave. and

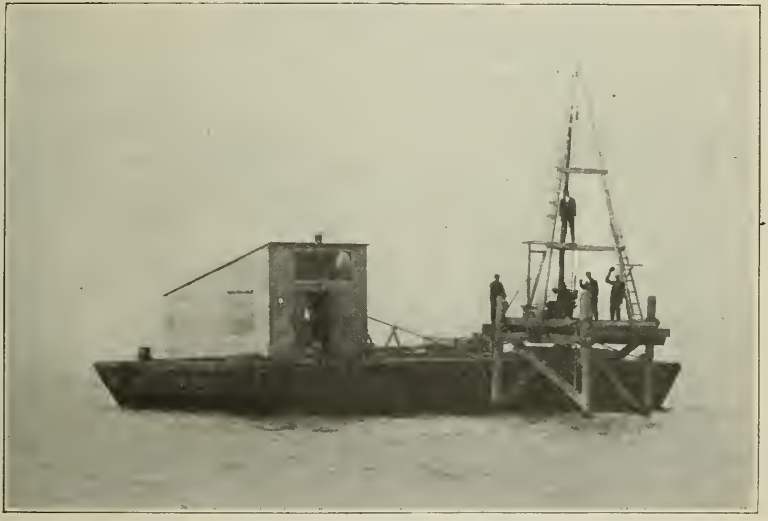

Fig. 7. Boring Platform in Place and Diamond Drill at Work.

Montrose ave. and in Wilson ave. and Montrose ave. between Clarendon ave. and the lake shore, as well as all the enclosed angles, the length of a line connecting points on lake shore at Wilson ave. and Montrose ave. was calculated. This was necessary because the line passed over the water and could not be measured. With this calculated line as a base line of a triangle (A) with the Wilson ave. crib as the third point, all three angles being measured, the distance from the Shore shaft was calculated by law of sines.

Additional triangulations were made to check triangle "A." Using the same line on Montrose ave. with the transit set up over the point on the southwest corner of Montrose ave. and Clarendon ave., a line was run on the west walk of Clarendon ave. to the point

on the northwest corner of Sheridan road and Clarendon ave., the angle being read 89°48′00″ and the line measured 3,254.70 ft.

Setting the transit over the point on Clarendon ave. and Sheridan road, a line was run to the point on Sheridan road and the Lake Michigan. This line measured 1,305 ft. The angle between these lines was read 86°33′25″. With these three sides and the two angles, the line along the shore between the point on Montrose ave. and the point on Sheridan road was calculated, and served as a base line for a triangle (B) which was formed by the point on Montrose ave. and Lake Michigan, the point on Sheridan road and Lake Michigan, and the Wilson ave. Crib—all angles being read. Calculating triangle "B," which has one side in common with triangle "A," it was found to check very closely with the common side of triangle "A."

A third triangle, "C," was formed with the three points on the shore of Wilson ave., Montrose ave. and Sheridan road. With the base lines of triangle "A" and "B," and the angle between them read, triangle "C" was calculated. With the calculated line connecting Wilson ave. point with Sheridan road point, as a base line, and the crib as the third point, another triangle was formed having the line from Wilson ave and the lake to the crib as a side common with triangle "A." A solution of this triangle checked the side of triangle "A."

The length of Drift 1 was determined from a solution of the triangle formed by the side of "A" from the point on Wilson ave. bulkhead and the crib and portion of drift 2 extending east of the above point, and the angle between these sides which was read.

Returning to the results of these calculations, the base line of "A" is 1,435.61 ft., the angle at Wilson ave is 71°16′24″, at Montrose ave. 103°37′36″, and at the crib 5°06′00″. By calculation, the line from Wilson ave. point to crib is 15,695.04 ft.; the other side is 15,294.80 ft., by law of sines using trigonometric functions.

The base line of triangle "B" is 3,215.92 ft., the angle at Montrose ave is 85°17′18″, the angle at Sheridan road is 82°40′30″, and at the crib is 12°02′12″. Calculating this triangle the side common to "A" is found to be 15,295.48 ft., a difference of 0.68 ft.—by law of sines with trigonometric functions.

The calculation of triangle "C" gives the side common to triangle "A" as 15,695.06 ft., while the side of "A" is 15,695.04 ft. by law of tangents with trigonometric functions.

Calculating the triangle to determine the length and angle of Drift 1, it was found that Drift 1 is 2,011.37 ft. and makes an angle with the line to shore of 2°05′52″, the angle at shore was read 00°18′30″; the angle between Drift 1 and Drift 2 is 2°24′22″. The distance of the crib south of the line was calculated to be 84.46 ft. Calculations were made by using seven place logarithms and checked by seven place natural functions.

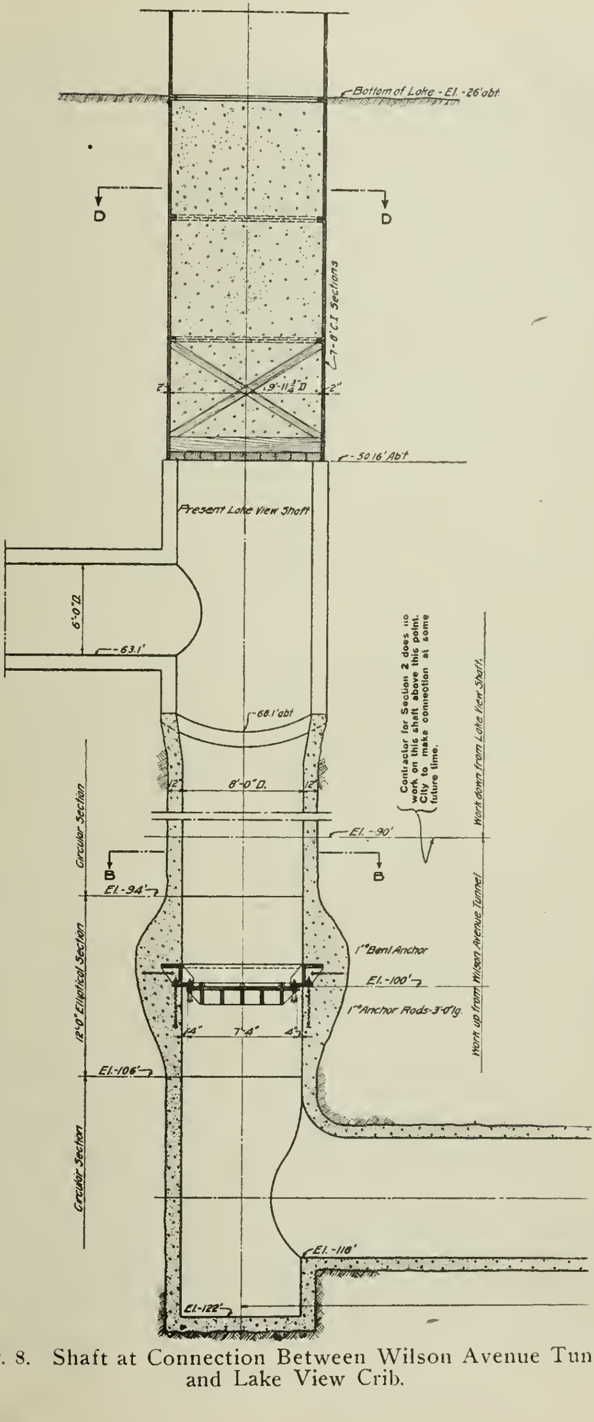

Fig. 8. Shaft at Connection Between Wilson Avenue Tunnel and Lake View Crib.

TUNNEL LINE

The actual tunnel line was determined by the Assistant Engineers with reference to the conditions which they had to meet in driving to a common point. The line of Drift 1 runs westerly from the crib to a point 13,882 ft. east of the short shaft on the center line of Wilson ave. extended east over Lake Michigan. Drift 2 extends from this point to the Wilson ave. shore shaft. The angle between Drift 1 and Drift 2 is 2°24′22″. Drift 3 runs westerly from the Wilson ave shore shaft on the same line with Drift 2 which is the center line of that portion of Wilson ave. east of Racine ave. At a point 2,689.44 ft. west of the shore shaft, Drift 3 bears 00°16′30″ south and continues westerly to the connection with Drift 4 which is 3,401.0 ft. west of the shore shaft and 6,398.0 ft. east of the Lincoln ave. shaft.

Continuing westerly in Drift 4 for a distance of 1,398 ft. from the connection with Drift 3, the line of Drift 4 bears 00°10′00″ south and continues westerly to the stub drift on which the Lincoln ave. shaft is located. Drift 5 starts at this point and runs west on the same line with Drift 4 to a connection with Drift 6 expected to be at a point 2,206.0 ft. west of the Lincoln ave. shaft.

Drift 6 will presumably end at this point, and continue west to a point 5,164.8 ft. east of the Lawndale ave. shaft. At this point Drift 6 bears 1°27′20″ north and runs to the Lawndale ave. shaft.

Drift 7 runs west from Lawndale ave. shaft 2,871.9 ft. bearing slightly south from Drift 6 to the connection with Drift 8, and Drift 8 continues west from this connection to a shaft at Mayfair which is 4,837.0 ft. west of the connection with Drift 7.

Drifts 7 and 8 are on the same line which makes an angle of approximately 2°24′22″ with Drift 6 at the Lawndale ave. shaft.

A stub connection 72 ft. farther is constructed for future extension to the east line of N. Lamon ave. and is known as Drift 9.

The main working shaft at Mayfair is not on the line of Drift 8 but is a 12 ft. connection to Drift 8. This connecting tunnel bears 65°59′00″ north from the line of Drift 8, and is 76.2 ft. long.

To locate the line of drifts 7 and 8, which could not be run out on the surface on account of the diagonal district previously referred to, a triangulation survey was made by sighting from a point on the construction trestle at Mayfair shaft to a point on the headhouse over the center of the shaft at Lawndale ave. and to the center of the gate shaft on drifts 8 and 9. Also, a sight was made to a point on the trestle from the headhouse at Lawndale and the above mentioned gate shaft at Mayfair. Also the distance between this point at the gate shaft and the point on the trestle was measured. The third side of this triangle was the tunnel line which had been determined previously by a traverse line from the Mayfair shaft to the Lawndale ave. shaft. This traversed tunnel line was found to

check closely with the triangle formed by the two shafts and the point on the Mayfair shaft trestle.

The traverse around the district between Crawford ave. and Kildare ave. was run from a point on the tunnel line at the west line of Crawford ave. to a point on the tunnel line at Kildare ave. The traverse started at a point on the west line of Crawford ave. 17.68 ft. south of the north line of Wilson ave. and turning 90° south from the tunnel line. This traverse continued to a point on Sunnyside and Crawford aves. 744.62 ft. from the first point. The traverse continued on a line turned 90° from the first line for a distance 663.59 ft. on Sunnyside ave. to a point on Kasson ave., then turned 135°59′20″ and ran northwest on Casson ave. 315.94 ft. to a point on Keeler ave., then turned 90° to a line running southwest on Keeler ave. 646.74 ft. to a point on Keokuk ave., then 90°7′10″ to a line running northwest on Keokuk ave. 1,096.96 ft. to a point on Kildare ave., and then turned 133°53′30″ to a line runnigg north on Kildare ave. 229.73 ft. to a point on the tunnel line on Wilson ave.

From this traverse, by calculating latitudes and departures, it was found that the length of the surface line between the two points was 2,130.69 ft.

One of the features of the tunnel survey was the method of making an overhead check on the connecting tunnel to the Lake View Crib. This overhead work comprised a diamond drill boring made on the tunnel line at a point 119.88 ft. east of the Lake View Crib. A buoy was set on the tunnel line by sighting from shore and also in line with two points previously established on the Lake View Crib.

A boring platform of piles 16 ft. x 32 ft. was constructed over this point and the tripod of the boring machine was set by sighting with a transit on the tunnel line from the shore. The boring was sunk to elevation —118. which is about 6 ft. below the springing line of the tunnel. The hole in the rock was 1¾ in. in diameter, and a 1 in. pipe, about 18 ft. long, was placed in the hole. The pipe was grouted in with cement at the bottom of the hole, and left there to be found when the tunnel was excavated to that point. After the boring had been completed the platform was used to make an overhead survey to tie in the underground work with the Lake View Crib.

The transit was set on the platform over the boring and sighted on a plumb-bob suspended over the center of the intake shaft inside of the Lake View Crib. To obtain this sight it was necessary to make a hole in the outer wall of the crib, and also a hole in the well room wall. When the transit had been sighted on the bob over the intake shaft, the telescope was turned to the sight on the tunnel line on shore. This was repeated twice. The distance from the boring to the center of the shaft was carefully meas-

ured. As the distance of the platform from the crib breakwater was nearly 200 ft. a steel tape 200 ft. long was used.

A point was set on the Lake View Crib platform on the connecting tunnel line, and its distance from the boring was carefully measured. Another point was set on the Lake View Crib platform and the distance between these two points was measured. The transit was set up over the point on the connecting tunnel line and sighted on the boring, and then the angle between the connecting tunnel line and the line on the crib platform was read. The transit was then set up over the second point and the angle between the boring and the line on the crib platform was read. With these two angles, and the line on the crib platform as a base line, the distance from the boring to the point on the connecting tunnel line was calculated and found to check exactly the measured distance.

This miniature triangulation was made from a base line 52.06 ft. long measured off on the crib platform and the angle which this line made with the connecting tunnel line, 104°22′10″, and the angle between the base line and the boring with the transit set up over the second point of the base line 63°38′40″.

The distance to the boring from the shore shaft was calculated from the base line of triangle "A" of the Wilson ave. Crib triangulation and angles read with the transit set up at the points at the ends of the base line. When the tunnel had been excavated to the calculated distance the pipe left in the boring was found. The actual distance of the boring from the shore shaft checked within 4 ft. with the calculated distance. This was considered satisfactory because the platform and tripod moved during observation with the wind and water, and it was difficult to catch a sight with the transit.

The pipe for line was found to be 3 in. north of the tunnel line which was considered remarkable.

The triangle obtained for calculation of the distance of the boring from the shore shaft comprised a base line of 1,435.61 ft. long, and the angle at the Wilson ave. point on the bulkhead was 71°34′00″ and at the point on Montrose ave. the angle was 100°26′45″. The distance from the shore shaft was calculated to be 10,356 ft. The boring was found in the tunnel at 10,352 ft. from the shore shaft.

METHODS OF UNDERGROUND SURVEY

The method of plumbing the shafts for transfer of the overhead line into the tunnel was alike on all sections of the tunnel.

This method comprised the use of two ordinary transits, reading to 20″, and two plumbing wires from 6 to 10 ft. apart, each carrying a plumb-bob weighing about ten pounds.

The procedure followed in plumbing each shaft was to first carry the line over the shaft by a transit set up on the surface line. The two wires (of No. 1 piano wire) were suspended from the headhouse on this line to the bottom of the shaft.

The transit man on top kept these line wires carefully on line by continual observation. All pumps, the cage, and all other work about the shaft was stopped. The engineeer blow adjusted the plumb-bobs so as to allow them to hang freely in pails of oil. The oil used was sufficiently thick to prevent the bobs from swinging widely, and served to bring them to rest more quickly than water would do.

The crew on top would signal by tapping on a pipe when the wires were set on line.

The crew below, on receiving the signal, would set up their transit on the line of the two wires in the back drift from the one which was to be lined up. The transits were close to the wires, about 50 ft. When the bobs had come to rest the observer would carefully shift the transit until on exact line with the wires, then set a point in the roof of the tunnel close to the shaft and at least one more point nearer the face of the drift. The distance between plumbing wires (6 to 10 ft.) served as the base line on which the underground line was based.

All the shafts were plumbed three or more times while excavating the first 2,000 feet of tunnel, and about once for each 2,000 feet beyond that point.

The later plumbing check the stability of the points previously set and also the accuracy of the points carried to the face of the drift from the original points.

The line points are spuds driven into wooden plugs set in drilled holes in the roof. These holes are about 6 in. deep and two in. in diameter. A horse-shoe nail with a small hole drilled for the eye is used for a spud.

In some of the drifts platforms were used for transit work. These were built high enough to allow trains and men to pass freely underneath, and in this way the instrument work was carried on without interfering with the work in the tunnel. A trivet was used on platforms instead of a tripod. The transit was set up under the point in the roof from which a plumb-bob was suspended. Grades were carried forward from plugs set in the side of the drift.

For centering the face of the drift for drilling the line was usually sighted in by the plummet lamps. Sometimes the grade was carried into the face by using plummet lamps, and at other times by using a straight edge about 10 ft. long. Hand-levels were tried but found unsatisfactory.

Three of the shafts being on the line of the tunnel, the surface line was transferred directly to the drift. Two other shafts were located away from the tunnel line to which they were connected by stub drifts, and it was necessary to turn an angle the same as on the surface between the shafts and tunnel line. This angle was checked by repeating the plumbing operations.

In the long drift under the lake (drift 2) from the shore shaft,

a novel method of telephone aid was used to speed up the work of checking the line from the shaft to the heading.

Beyond station 14+00, the points were set about 1,000 ft. apart. Three "sight-boxes" were used for foresights, and no backsights were taken. These sight boxes were made to contain two clusters of two 60-watt tungsten lamps, connected to a piece of extension wire plugged into a socket on the lighting wires along the wall. A plumb-bob was suspended from the line point in the roof between the clusters and sighting was done on this bob. The first box was set at a point about 1,400 ft. from the shaft.

After setting the first sight box, the rodman went forward about 1,000 ft. to the next point, and awaited the observer's signal to place the second box.

The observer and the rodman each carried a telephone hand set which were connected to the tunnel telephone wires by scraping the insulation from the wires and making a connection.

The observer sighted on the first box, and when he had the vertical hair on the plumb-bob, he would hammer on the power air pipe. The rodman, on hearing the signal, would answer on the telephone, and would then be directed on the telephone to place the second sight box and bob.

When this plumb-bob was carefully set on the line with the first sight, the rodman would take his telephone and the third sight box to the next point, about 1,000 ft. beyond. The rodman's helper would return to the first sight box and remove it for the observer to set the transit at that point. The helper would remain and aid the observer in setting up the instrument, then take the sight box forward to the rodman. The instrument man would foresight on the second box and, as before, sight forward to the rodman and set that point. This operation was repeated until the line was checked into the heading. By this use of the telephone much longer sights were used and also much walking backward and forward to receive instructions was eliminated. Only the helper was compelled to double back on the trip and the entire drift (now 13,000 ft. long) was checked in a single day.

Measurements were made with ¼ in. steel tapes and corrections made for temperature. Permanent points were set on the triangulation surveys and also on the preliminary and location lines. These points were either copper plugs or iron bolts set in the concrete walk or pavements and center punched.

On Sept. 11, 1917, the connection between drifts 1 and 2 was made at a point 14,848.8 ft. east of the Shore shaft.

This connection was practically perfect for line and only .10 ft. out on grade. About 100 ft. before the connection was made, the tunnel was driven gradually to the north of the instrument line, because the assistant engineer was of the opinion that his instrument line was a little south of the true line. This subsequently

proved to be the case as the instrument lines were actually 17 in. apart while the connection was perfect.

The connection between drifts 3 and 4 was within 1.2 ft. and drifts 7 and 8 met within 0.2 ft.

All work was done by Assistant Engineers, E. P. Scott, C. D. Golden, Paul Lippert, F. C. Martini and F. A. Smith working under the direction of Mr. Geo. F. Samuel, Assistant Engineer of Water Works Construction, and the writer, Engineer of Water Works Construction, in charge of the Construction Division of the Bureau of Engineering, Department of Public Works. Mr. John Ericson is City Engineer, in charge of the Bureau of Engineering, and under the Commissioner of Public Works, at present Hon. Frank I. Bennett.

A CORRECTION

Our attention is called to an error which may be found in "Processes of Sewage Treatment" by Harrison P. Eddy, on page 835, Volume XXI, December, 1916. In tabulating the comparison of costs, the construction cost was added to the capitalized, operating, interest and depreciation costs. It is manifestly incorrect to include both the depreciation and construction costs in this tabulation.

Table 6 should, therefore, read as follows:

COMPARISON OF COSTS OF IMHOFF TANK-TRICKLING FILTER PLANT AND ACTIVATED SLUDGE PLANT.

Item.	Trickling Filter Plant	Activated Sludge Plant.
Operating Expenses	$ 17,080	$ 40,140
Interest and Depreciation	26,760	19,780
Total Annual Cost of Treatment	$ 43,840	$ 59,920
Total Annual Cost of Operation per m. g.	21.84	29.85
Total Annual Cost of Operation per capita	0.80	1.09
Expenses Capitalized at 4 per cent	$1,096,000	$1,498,000
Difference		$ 402,000

The paragraph at the bottom of the same page reading "In addition to this annual saving there would be also the saving in investment cost of $36,000," should be entirely omitted.

IN MEMORIAM

CHARLES SUMNER HALL
DIED JUNE 15, 1917

CHARLES SUMNER HALL
Member Western Society of Engineers
Died June 15, 1917.

Mr. Charles Sumner Hall died June 15, 1917, after a short illness, at his home in Evanston, Illinois.

Mr. Hall was born in Richford, Wisconsin, January 21, 1857, moving to Eldora, Iowa, with his parents and living there until 1884. He was graduated from the Iowa State University as C. E. in 1880 and immediately entered the service of the Chicago & North Western Railway Company on the construction of the line from Eagle Grove to Hawarden. On the completion of this work in 1882, Mr. Hall had charge of the location and construction of the Diagonal Railway, now that portion of the Great Western Railway from Des Moines to Waterloo, Iowa. The years 1885 and 1886 were spent in constructing single track railway from Dows to Garner, Iowa, which is now a portion of the Rock Island Railway system. The next two years were spent in locating and constructing for the Soo Railway one hundred miles through the upper peninsula of Michigan. In the spring of 1888 Mr. Hall entered private practice in the central part of Iowa, laying out various County drainage propositions. In 1891 he again entered the service of the Chicago & North Western Railway Company as an Assistant Engineer on the Winona-St. Peter Division and was shortly appointed Division Engineer of this Division. In 1899 he was appointed Locating and Constructing Engineer on the Railway Company's line from Burt, Iowa, to Sanborn, Minnesota, a distance of ninety-four miles, later becoming Division Engineer of the same Division and holding such position until January 21, 1901, when he was appointed Engineer of Track Elevation for the Railway Company at Chicago, in which position he continued until his death. Under his direction twenty-three miles of right of way have been elevated, involving the raising of two hundred miles of track, the construction of one hundred and forty subways, the placing of seven million yards of filling and one-half million yards of masonry, the total cost of this work amounting to $11,000,000.

While Engineer of Track Elevation Mr. Hall also had charge of various other projects, such as the construction of the Milwaukee State Line Railroad, a double track of road of the Chicago & North Western Railway Company, running from Lake Bluff to Milwaukee; the Des Plaines Valley Railway, a double track belt line from the Chicago & North Western Railway Company's Proviso Yard to a connection with the State Line Railway at Blodgett. Also various other work, such as Engine Terminal Facilities, etc.

The work embraced in the elevation of tracks of the Chicago & North Western Railway Company in Chicago and vicinity will always stand as a monument to Mr. Hall's skill as an Engineer. One of the out-standing traits of Mr. Hall's character was the singleness of purpose with which he carried out the work in his

charge; he was thorough, painstaking and efficient in all his undertakings.

Mr. Hall was married to Mary E. Elder of Garner, Iowa, on August the 6th, 1885. He is survived by his mother, wife, a married sister, two married and one unmarried daughters.

Mr. Hall became a member of the Western Society of Engineers May 13th, 1901. He was also a member of the Chicago Engineers' Club and the First Congregational Church of Evanston.

W. H. FINLEY,
GEORGE W. HAND,
GEORGE C. D. SMITH.

CHARLES C. STOWELL

Member Western Society Engineers,

Died August 10, 1917.

Charles C. Stowell was born in Mt. Upton, Chenango county, New York, on July 10th, 1851, the son of Young E. Stowell and Tempa P. (Shepard) Stowell. He studied Civil Engineering at the college at Fredonia, N. Y., and it was his purpose to follow the profession of teaching. He taught for seven years at Mexico, New York, but his health suffered from the confinement, and he was forced to seek an occupation which would keep him out of doors. He took up railroad work, and from 1883 to 1890 was engaged in railroad work in Missouri, Iowa, Illinois and Michigan.

In 1890 Mr. Stowell went to Rockford, Ill., as Assistant City Engineer. He was appointed City Engineer in May, 1892, and occupied that position until May, 1897. During his connection with the City of Rockford, the public works began to assume much importance. Mr. Stowell successfully undertook the design and construction of many pavements and street improvements, various river bridges, numerous sewer extensions and water works improvements which were built during that period. One of Mr. Stowell's noteworthy achievements was the design and construction of a concrete reservoir with an arched reinforced concrete roof. This was constructed in 1893, before reinforced concrete had been extensively adopted, and it was quite novel, exciting much interest among engineers.

After Mr. Stowell retired from official life, he took up the design and construction of concrete and especially reinforced concrete work in the country in and about Rockford. He designed and built many reinforced concrete buildings, arch bridges and monolithic reinforced concrete chimneys.

Mr. Stowell was a man of kindly personality which was ever manifest in his domestic and social relations. He possessed high ideals, was scrupulously honest and sincere, absolutely dependable,

and while exceedingly conservative in professional work, always possessed the courage of his convictions when he had once satisfied himself of the correctness of his views.

Mr. Stowell was married in Rockdale, N. Y., June 25th, 1878, to Miss Alice L. Grogory, who survives him. He is also survived by two sons, Edward B. Stowell of Charles City, Ia., and Arthur G. Stowell of Rockford, and two daughters, Mrs. Fannie Loomis of Sidney, N. Y., and Miss Laura Stowell of Rockford.

In August, 1915, Governor Dunne appointed Mr. Stowell as one of the original members of the Illinois State Board of Examiners of Structural Engineers, in which capacity he served the state and profession until just prior to his death. He was a member of the Illinois Society of Engineers and its president during the years 1896 and 1897. He was elected a member of the Western Society of Engineers on March 1st, 1893.

J. T. HANLEY,
DANIEL W. MEAD,
H. J. CARLSON,
W. D. GERBER.

WAR SERVICES

All members of the Western Society of Engineers who are in the service of any branch of the army or navy, either as commissioned officers or otherwise, or are engaged in civilian work for any branch of the government due to the war, are requested to notify the undersigned promptly in order that a complete record may be kept of the services rendered to the Government by the Society membership.

The Society will also be glad to receive the photographs of all its members who are in service. An album will be prepared so these can be kept in the Library of the Society.

EDGAR S. NETHERCUT, Secretary.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings.

Meeting No. 976, September 10, 1917.

The regular meeting of the Society for September was called to order at 8:00 p. m., by President Burt, with about forty members and guests present.

The President announced the election of Mr. Edgar S. Nethercut, M. W. S. E., as Secretary.

The Secretary announced the approval of the officers elected at a special meeting of the Mechanical Engineering Section held August 2nd, as follows:

Chairman: Prof. G. F. Gebhardt.

Vice-Chairman: Paul L. Battey.

Directors: C. H. Norwood, J. L. Hecht.

The Secretary also announced the death of Mr. E. L. Ransome, M. W. S. E., and Mr. C. C. Stowell, M. W. S. E.

The President announced the election of members as follows:

No. 38, Edward L. Parsons, Affiliated Member.

Announcement was also made of the presentation of the colors to the First Regiment Illinois Engineers on Monday, August 27, 1917.

The President then introduced the speaker of the evening, Mr. F. D. Flint, President of the National Suspended Monorail Company, who presented a paper on the subject of "The Monorail as a Method of Transportation and How It Can Be Applied to Chicago," which was illustrated by lantern slides.

The meeting adjourned at 10:30 p. m.

Excursion and Inspection Trip.

Upon the invitation of Com. W. A. Moffett, the Society visited the United States Naval Training Station at Great Lakes, Illinois. This trip was made by about 150 members and guests.

On arrival at the Great Lakes Station, the members were met by officers of the Training Station and escorted to a convenient stand on the roof of the Administration Building for the inspection, drill and dress parade. On completion of this drill, under the guidance of the officers, the party was escorted about the grounds and visited the various camps under construction, including the water and sewer supply buildings, roads, etc. A very complete opportunity was given to understand the difficulties of construction under the strenuous conditions and for the appreciatiton of the very excellent results which have been obtained.

Journal of the Western Society of Engineers

Vol. XXII OCTOBER, 1917 No. 8

EFFECT OF FIRE ON THE FLAT SLAB BUILDING OF THE QUAKER OATS CO., PETERBORO, ONT., DEC. 11, 1916

By T. D. Mylrea, *Assoc. W. S. E.**

Presented May 14, 1917.

On December 11, 1916, the plant of the Quaker Oats Company at Peterboro, Ontario, was visited by a fire which destroyed practically the entire plant. This fire is of exceptional interest, not only because of the unusual volume and great intensity of the heat

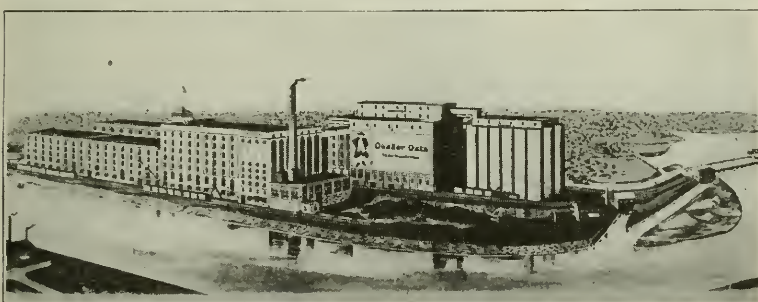

Fig. 1. General View of Plant before the Fire.

developed, but also because one of the buildings was of the flat slab reinforced concrete type of construction. It is to the effect of the fire on this building that our attention will chiefly be confined.

DESCRIPTION OF PLANT.

The plant previous to the fire is represented by Fig. 1 and Plate 1. It extends in a general northerly and southerly direction, the right-hand end of Fig. 1 being to the north. The view is therefore taken from the northeast. The low building in the foreground is the Boiler House, and the fire pump was located in the low shed to the north of it. Next to the Boiler House, on the south, is the Dry House, identified by the four blank wall panels, where the fire started. The Mill adjoins the Dry House and is separated from

*General Inspector, City Architect's Department, Toronto.

it by a fire wall. The four story buildings to the south of the Mill are Warehouses No. 1 and 2, respectively, which were separated by another fire wall. The mill and Warehouse No. 1 were separated by a fire wall, and the offices were located on the first floor of Warehouse No. 2, at the extreme south end.

In the background, at the right end of the picture, are shown eighteen circular reinforced concrete Grain Bins, and to the south of these an Elevator of wooden crib metal-clad construction. The brick building adjoining the Elevator on the south is the Cleaning

Fig. 2. One-half Hour after Fire Started, the Dry-house was Totally Destroyed, and the Mill was a Mass of Flames.

Mill, where the grain was cleaned before passing over the enclosed bridge to the top story of the Dry House. The reinforced concrete Warehouse, in which we are interested, may be seen over the roofs of the Warehouses first mentioned. About one quarter of a mile upstream was a Hydro-Electric Station, belonging to the Company, which furnished the motive power for the plant, the steam generated in the Boiler House being used in manufacturing processes and to supply the fire pump only.

Warehouses No. 1 and No. 2, the Mill, Dry House, Boiler House, Pump House and Cleaning Mill all had brick walls on stone foundation, and all except the Boiler House had plain glass windows in wooden sash. In the Boiler House the windows were plain glass in solid steel sash. The south wall of the Cleaning Mill was blank, and

the windows in the east wall as well as those in the west wall of the Dry House were equipped with wood-tin-clad fire shutters. The first story of the Elevator was brick on stone basement walls; and above this 2 by 6 in. and 2 by 8 in. yellow pine cribbing was used for bins and walls, the wooden walls being covered with galvanized iron. Plain glass windows in wooden sash were used in the Elevator also. The concrete Grain Bins were each about 22 ft. outside diameter and had shells 7 in. thick reinforced by ¾ in. longitudinal rods at about 2 ft. centres and by circumferential bands about 1½ in. by 5/16 in. at 8 to 10 in. centres.

From Plate II it will be noted that Warehouses No. 1 and No. 2 and the Mill were of "semi-mill" construction; wooden posts,

Fig. 3. This Picture indicates the Blast-furnace-like Conditions in the Concrete Warehouse during the Afternoon.

girders, beams, floors and roofs being used. The Dry House had concrete floors on non-fireproofed steel beams and columns. The first floors of these buildings were on the same level, as were the sixth floor and top balcony in the Mill and Dry House, but all other floors were at different elevations. The doors were in consequence neither numerous nor large. With the exception of one door in the basement and one in the first story there was no direct communication between the Mill and Warehouse No. 1, it being necessary to go through the elevator and stair tower to get from one building to the other. As all door openings had wood-tin-clad fire doors the fire was stopped for quite a little while at this wall.

Plate III gives the details of the concrete building. It was approximately 60 ft. wide, 280 ft. long, and basement and six stories high. The first four stories were built in 1910 and the two upper ones early in 1916, the Canadian Leonard Construction Company, Limited, being the Engineers and Contractors for both the

upper and lower sections of the building. The floors were designed for 200 lbs. per sq. ft. live load. In the first four stories there were no drop panels at the top of the columns, and the column caps decreased in diameter with the columns. There was more steel in the diagonal bands of reinforcement than in the direct bands, and

Fig. 4. The Concrete Warehouse at 9:55 p. m., nearly 12 Hours after Start of Fire. Collapsed Portion may be seen at the Left.

the circular reinforcement of the column shafts consisted of separate steel hoops about 1½ in. by ¼ in. section spaced about 8 in. centres

The upper two stories show the column capital of constant diameter, the drop panel, the more recent practice in the distribution of the slab steel, and the spiral form of circular column reinforcement. For some reason or other, the drop panels were omitted from around the caps of the wall columns in these upper stories and a bracket substituted, but on the corner columns these brackets were lacking. Since drop panels would not have interfered with the windows, it is hard to tell just why they were omitted, for at these

Fig. 5. The Concrete Warehouse at 10:15 p. m., just 12 Hours after Start of Fire. The Collapsed Portion.

places the bending moments are most severe. It might have been that the type of construction adopted required less work on the forms.

When the two upper stories were erected it was decided to increase the diameter of the interior columns in the third and fourth stories to aid them in carrying the additional load. This was accomplished by wrapping them in expanded metal and pouring

Fig. 6. Taken by Its Own Light at 10:30 p. m.

around them a rich grout of cement and gravel screened through a ½ in. mesh screen. The fifth floor—the former roof—was increased from 7 in. to 9 in. in thickness by laying wire netting upon it and pouring on another 2 in. of concrete.

The cement used for both upper and lower sections was Canada Cement. While we have no authentic tests of the cement used on the job, the following figures are an average of 53 tests upon Canada Cement used on the Robt. Simpson Mail Order Building recently constructed in Toronto:

Initial set	3 hrs. 35 min.
Final set	7 hrs. 30 min.
Held on 100 mesh sieve	3.2%
Held on 200 mesh sieve	18.5%
Tensile strength— 1 day neat	381 lbs. per sq. in.
Tensile strength— 7 days neat	615 lbs. per sq. in.
Tensile strength—28 days neat	751 lbs. per sq. in.
Tensile strength—7 days, 1 cement to 3 sand	292 lbs. per sq. in.
Tensile strength—28 days, 1 cement to 3 sand	419 lbs. per sq. in.
Soundness Tests O. K.	

The reinforcement used in the part constructed in 1910 was a medium steel. Tests of samples of ½ in. ϕ rods taken from the site after the fire give the following results:

Yield Point	47,300 lbs. per sq. in.
Ult. Str.	72,500 lbs. per sq. in.
Elong. in 8 in.	23%
Reduction of Area	59%

In the upper two stories munition stock arbitrary discard was used for reinforcement. The following results were obtained from tests on ½ in. ϕ rods taken from the site after the fire:

Yield Point	60,000 lbs. per sq. in.
Ult. Str.	98,100 lbs. per sq. in.
Elong. in 8 in.	16%
Reduction of area	43%

Many tests were conducted upon reinforcing rods made from this munition stock before it was approved as a suitable material for use in Toronto, and following is a summary of these tests:

Rods ½ in. ϕ and ⅜ in. ϕ

Yield Point	46,400 lbs. per sq. in.
Ult. Str.	68,800 lbs. per sq. in.
Elong, in 8 in	25½%
Reduction of area	60%

Rods 1 in. ϕ to 1¼ in. ϕ

Yield Point	50,900 lbs. per sq. in.
Ult. Str.	83,400 lbs. per sq. in.
Elong, in 8 in	23%
Reduction of area	40%

It is impossible to state whether or not the properties of the steel were affected by the heating and cooling, but from a comparison

of the above values it would appear that the steel was satisfactory, and that if anything it was made stronger and more brittle.

The aggregate used throughout was a local gravel of good quality, consisting largely of limestone pebbles with an admixture

Fig. 7. Only the Metal Parts of Freight Cars are Left and These are a Semi-fused Mass.

of granite pebbles. It was well graded but contained stones that would not have passed a 2 in. ring.

The brick used for the face of the walls was a red stock brick, made of clay and machine molded; and the lining bricks were a gray stock brick, similarly made.

The north wall of the building was blank. The east wall, fac-

ing the lane between the reinforced concrete building and Warehouse No. 1 had a large number of windows with metal sash and wired glass. The sash and frames in the first four stories were of hollow metal, and in the upper two stories were of solid steel. On the other two sides of the building ordinary wooden frames and sash were used, with the exception of the north bay on the west side, in which the windows were the same as on the east side.

As may be seen on Plate I there was a concrete bridge in the third story between the concrete Warehouse and Warehouse No. 2 and a concrete tunnel between it and the Mill. There was also a stone tunnel from the Dry House to the Cleaning Mill in the basement and a bridge in the top story. The occupancy of the various buildings and the processes carried in each are shown, and are such

Fig. 8. Cracks due to Expansion of Floors in Concrete Warehouse.

as are incidental to the milling industry. It is known that grain dusts are highly combustible, even explosive, so that when the fire was once started it spread with great rapidity. There was a great quantity of combustible material in the concrete Warehouse, feed, paper, box shooks and the like, particularly toward the north end; and it will be noted that the north end is the portion that collapsed.

The insert in the upper right hand corner of Plate I shows that the Quaker Oats Plant was on the eastern edge of the water system of Peterboro, and was enclosed in a loop formed by City mains on Quaker and Hunter Streets and a yard main on the north and east. All the buildings of the plant except the concrete Warehouse and the Grain Bins were equipped with automatic sprinklers supplied from this yard main.

THE FIRE.

The fire was started about 10:15 a. m. by an explosion in the Dry House. The exact cause of the explosion has not yet been determined, but is under investigation by Provincial Fire Marshal Heaton. Both the north and east walls of the Dry House were blown out by the intensity of the explosion, and as the plant was in operation and all fire doors open, the Mill was filled with fire on all floors at the same time. The fire spread rapidly through the Mill, but was kept from breaking into the Warehouses for a little while by the wall and by the double barrier of fire doors which the employees of the Quaker Oats Co., under the direction of the Superintendent, managed to get closed before the fire got that far.

Figure 2 taken at 10:45 a. m., will give some idea of the intensity of the fire in the Mill, for blasts of flame about 30 ft. long

Fig. 9. Fused Structural Steel from Ruins of Dry-house.

may be seen shooting out over the roof of Warehouse No. 1. The fallen walls of the Dry House can also be seen. It will be noticed that there was a fair easterly wind, which drove the flames across the lane into the Cleaning Mill and Elevator, and when the Mill and Warehouses No. 1 and No. 2 were on fire, subjected the concrete Warehouse to a fearful exposure.

About 11:00 a. m. the contents of the reinforced concrete warehouse began to blaze, the fire starting on the third and fourth floors

where there were large piles of box shooks. An attempt was made by employees to close such windows as were open and to get a stream of water on the blaze. They succeeded in closing all except one of the windows, but could not reach that, because of the fire. A line of hose was connected to hydrant H (see Plate I) and some

Fig. 10. Interior Brickwork was Fused as Shown in This View of Elevator Enclosure.

of the employees carried it up to the burning box shooks, while others tried to turn the water on. However, as is explained under heading "HOW FIRE WAS FOUGHT" no water could be secured from this hydrant, owing to the lack of pressure, and the men were forced to leave the building to the mercy of the flames. Some of these men

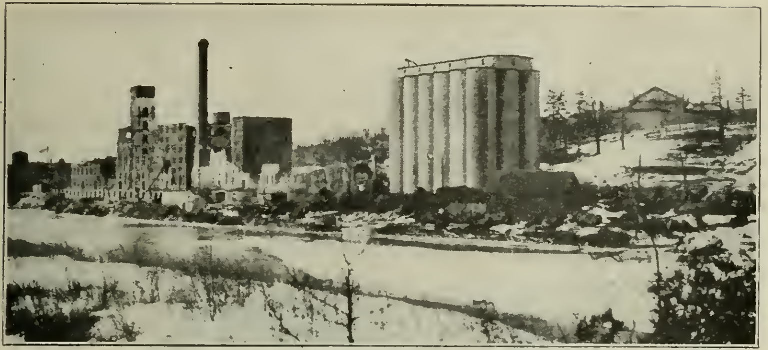

Fig. 11. This View is from the Same Point as Fig. 1.

barely escaped with their lives, so rapidly did the fire spread through the floors below them.

Figure 3 shows the blast-furnace-like conditions in the interior of the concrete building during the afternoon. It will be noticed that the wired glass in the east face of the building was hanging in sheets down the wall, and that the wooden frame and sash from the south wall are completely gone. It was in the west and front windows of the second and third floors that cast iron sash weights were

Fig. 12. Tangled Mass of Mill Machinery. Concrete Warehouse in Background.

found fused. The height of the blazing piles of material and the smokeless character of the flame can readily be seen. The fire raged in the concrete warehouse without one drop of water being poured on it till 6 p. m., when six and two-thirds bays north of the center of the building fell.

Figure 4 was taken by its own light at 9:55 p. m. and shows that the piles of material were still blazing fiercely. The collapsed portion may be seen at the extreme left edge of the picture. Figure 5, taken at 10:15 p. m., gives a closer view of the collapsed portion. The completeness of the ruin and terrific heat developed is readily discernible. Figure 6 was taken a little later, at 10:30 p. m.,

Fig. 13. General View of Concrete Warehouse. Note Condition of Metal Sash with Glass hanging from Sills.

from across the river, and the fire may be discerned in the windows in the standing portion of the reinforced concrete building in the background. Witnesses state that when this building collapsed the tremendous blaze from the loosened combustible material furnished a most awe-inspiring sight.

HOW THE FIRE WAS FOUGHT

In falling, the north wall of the Dry House buried the Boile house, thus cutting off the fire pump, and the east wall carried wit it a 6-inch sprinkler riser, at the same time burying the valve con trolling this riser. The fire in the Mill would naturally open u the sprinklers fed by the two 6-inch connections shown on Plate

with the result that with three 6-inch streams drawing from one 8-inch main the pressure was reduced to practically nil. Thus the private fire protection was put out of commission at the very start, and during the early stages of the fire the city fire brigade was badly crippled.

The fire chief said that the pressure was low for about 25 minutes, during which time the fire gained tremendous headway,

Fig. 14. Concrete Warehouse, looking North. One and One-third Bays still Standing.

and that since his 2½-inch hose streams were too small to be of use, he decided to save the surrounding property.*

The waterworks superintendent stated that on arriving at the fire he shut valve A to improve the pressure, then inquired of the superintendent and the fire chief if they thought it advisable to shut valve D. While this would have cut off all sprinklers and the

*From testimony before Provincial Fire Marshal.

Fig. 15. A Closer View of the Wreckage shown in Fig. 14. Note Columns with Hooping Exposed.

three private hydrants, it would have raised the pressure so that the public hydrants could have been used. They wished the water kept on as long as possible, to give the sprinklers any chance they might have. After waiting awhile, during which time the superin-

Fig. 16. The Floors in Many Places sag to Incipient Failure. See also Figs. 17 and 22.

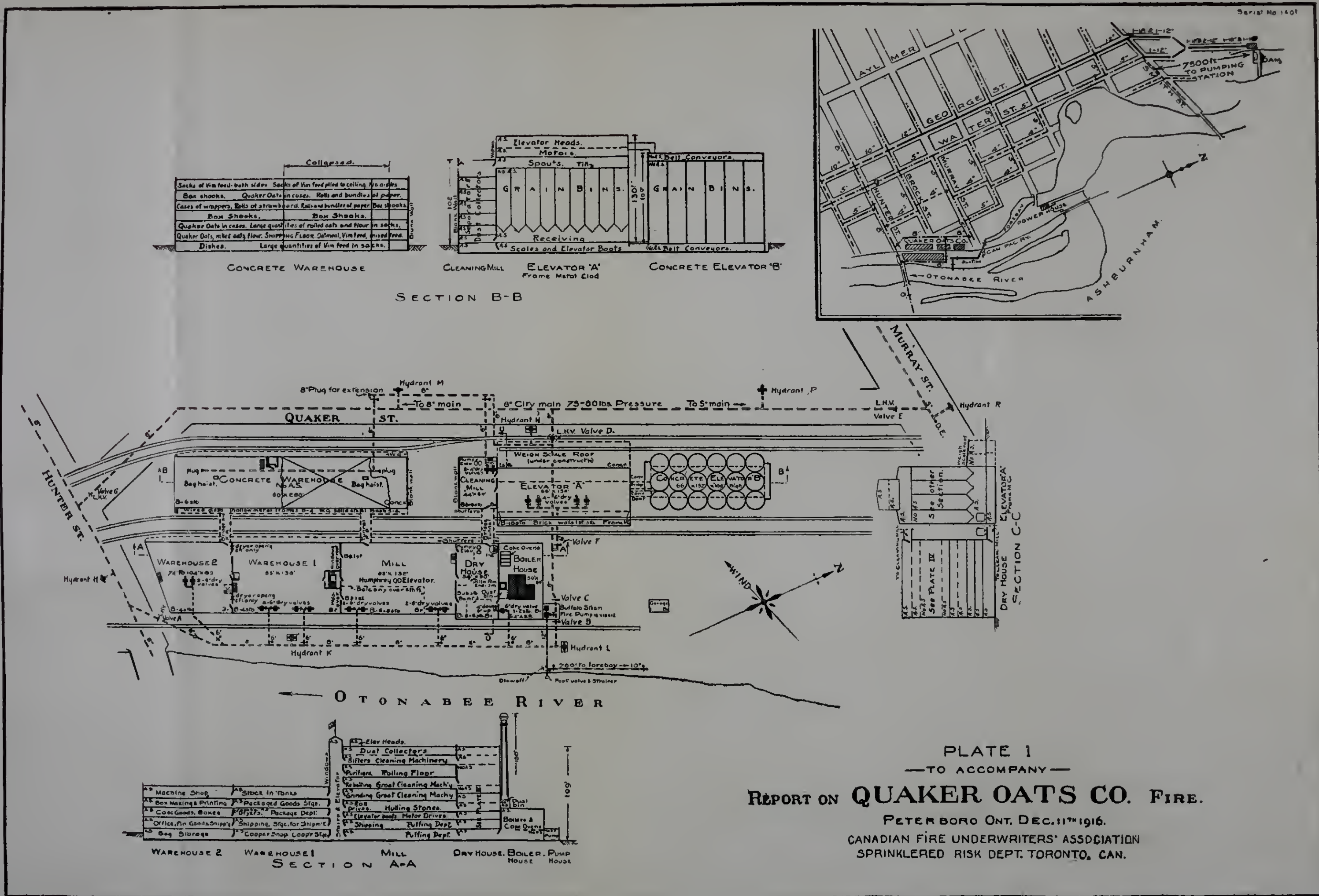

Plate I. General Plan of Quaker Oats Co. Plant at Peterboro, Ont., showing Location of Buildings and Sections. Insert shows Location in City.

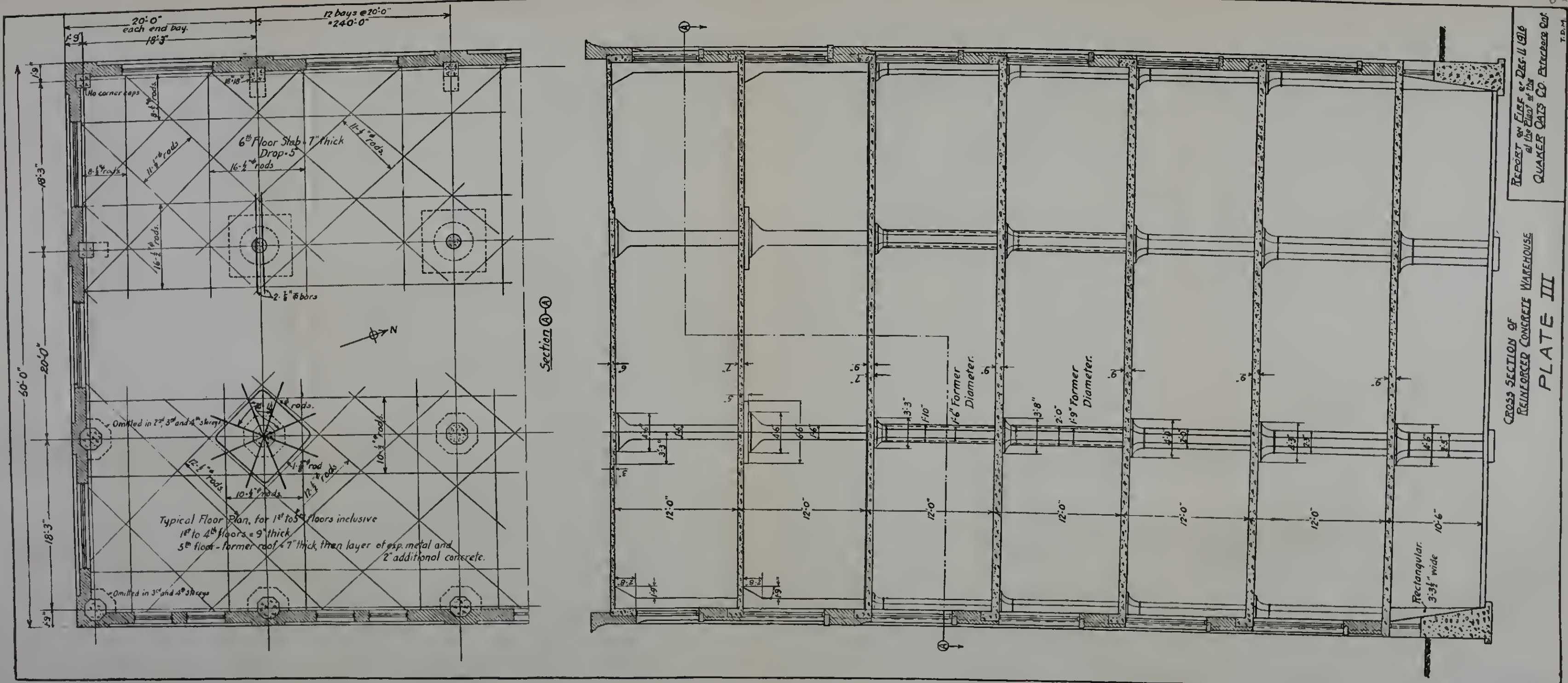

Plate II. Section through Warehouses, Mill, Dry-house, Boiler-room and Fire Pump House.

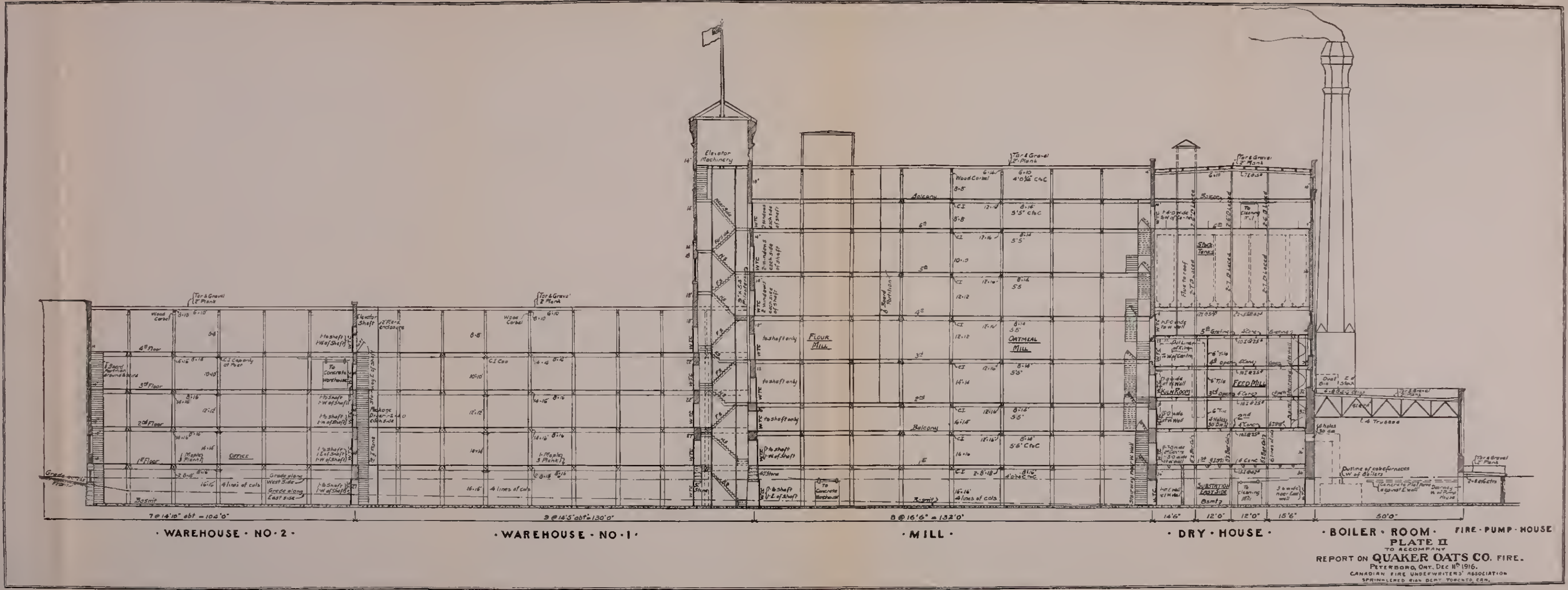

Plate III. General Construction of Concrete Warehouse.

tendent and the fire chief had left him, the waterworks superintendent decided on his own responsibility to shut valve D. However, owing to the heat and to the new construction on the west side of the Elevator, he could not locate the valve. He, therefore, shut valves G and E, thus cutting off all water supply except from hydrants R and H.*

It is interesting to note that if, after closing valve A, and having given up the Mill and Warehouses No. 1 and No. 2 for lost, valve B or C had been closed, the broken sprinkler riser would have been

Fig. 17. Another Ceiling View showing Condition of Floor Slabs. See also Figs. 16 and 22.

isolated, and full water supply conserved for the sprinklers in the Cleaning Mill, Elevator and all fire hydrants except K and L. If later it was felt that the Elevator was lost, valve F might possibly have been closed, saving the full water supply for public hydrants on Hunter street, Quaker street and Murray street. Valve D need not have been touched; and photographs taken during the fire show that valves B, C and perhaps F could readily have been reached, for bystanders can be seen in these photographs standing just about where these valves are located.*

It is regrettable that the proper public officials are not given the information concerning the location of private valves, for had the waterworks superintendent known their location, the judgment he used shows that he would have closed the proper one. The men in the Boiler House were all killed when the north wall of the Dry

*From Testimony before Provincial Fire Marshal.

House fell, so if they knew of the valves B and C, their knowledge was not available.

When the water pressure rose the fire brigade had all it could do to keep the fire from starting a conflagration in town, and did

Fig. 18. A Clear Plane of Cleavage Appears in Many Columns in Line with the Hooping. The Outer Shell can be Easily Removed with a Hammer.

not attempt to save the plant. As it was, the Court House, some 500 feet away, was damaged to the extent of about $20,000 and 15 or more lines of hose were kept busy putting out fires started in the neighborhood.

TEMPERATURES DEVELOPED IN THE FIRE

There is much evidence of intense and long-continued heat everywhere throughout the plant. The limestone foundations have been deeply calcined and spalled both inside and outside, and heat

Fig. 19. The Longitudinal Reinforcing Rods seem to be under Great Tension. Note Pencil Inserted in Contraction crack in Rod.

radiated from the fire in one building vitrified the bricks on the outside of the wall of another building across a lane 38 feet in width. The hose connections in hydrant M (see Plate I) which were set in lead, were melted out, although 60 feet away from the

burning concrete Warehouse. At many points about the plant freight cars were standing, and all but the metal parts were entirely consumed. Figure 7 shows one of these trucks in which the wheels have lost nearly all semblance of their original shape. In another case the wheels and the rails upon which they were standing were melted together and a section of the rails had to be cut out with the oxy-acetylene flame.

The temperature in the interior of the buildings must have been very intense for melted metal parts of machines may be found here and there in the ruins. Evidence as to the temperature developed in the reinforced concrete warehouse is given by the expansion cracks shown in Fig. 8. Owing to the heating of the floors and their consequent expansion, the length of the building considerably increased, and caused the peculiar diagonal cracks to appear in the brickwork. At the other end of the building the cracks run diagonally downward in the opposite direction.

Fig. 20. A Column in an Upper Story. The Hooping Encloses only a Small Part of the Column.

One curious effect of expansion due to heat was found in the elevator pent-house. The upper end of the elevator guides came to within an inch of the ceiling formed by the pent-house floor slab. Due to the expansion, these guides pushed two holes through this slab. As another instance, the roof drains were connected by swing joints to a 6-inch pipe running nearly the full length of the building, just under the roof. In expanding this pipe pushed the last swing joint before it, and in cooling and contracting pulled away from it about 5 inches.

Figure 9 shows fused structural steel removed from the ruins of the Dry House. In the front windows of the second story and in the front and some of the west windows on the third story of the concrete warehouse were found melted sash weights. In some cases they were but slightly fused, in other cases two or more weights had

Fig. 21. Column which had a Protective Coating. Concrete was Cut Away to Expose Reinforcing.

run together and in several places on the third floor the weights were reduced to shapeless masses of cast iron.

On the inside of the walls of all the buildings may be found large patches of fused brickwork, of which Fig. 10 gives an ex-

ample. This view was taken on the third story of the reinforced concrete warehouse. The melted brick ran down the face of the wall and out upon the floor like molasses, for a distance of about 18 inches, and over the doorway it trickled across the face of the concrete lintel and dropped from there to the floor. Upon breaking off some of this fused brick from the lintel, it was found that the concrete had been badly calcined beneath the running brickwork. In another place brickwork was found melted to a depth of 5 inches.

From the fact that cast iron melts at about 2,200 deg. F., and that brickwork reaches the stage of incipient fusion at about the same temperature, it must be concluded that at many places during

Fig. 22. Deflection of Wall Panels, indicating a Weakness at Bracket Heads. See also Fig. 23.

the conflagration temperatures of at least 2,300 deg. F. were reached.

GENERAL DISCUSSION OF DAMAGE TO BUILDINGS

Figure 11 gives a general view of the plant after the fire, from about the same location as Fig. 1. The Hydro-Electric station, owing to its distance from the rest of the plant, was not affected, and owing probably to the direction of the wind, the Grain Bins sustained very little damage. The lower 15 feet of the two east bins on the south end was somewhat spalled, and one small hole was burned through the wall of the more easterly of these two, but as this was below the level of the bottom of the bin, it did no damage

to the structure. About six weeks after the conflagration, however, fire smouldering in the corn in the southeast bin caused an explosion which blew off the top of the bin.

The rest of the buildings comprising the plant are completely ruined, not excepting the concrete Warehouse, although enough of

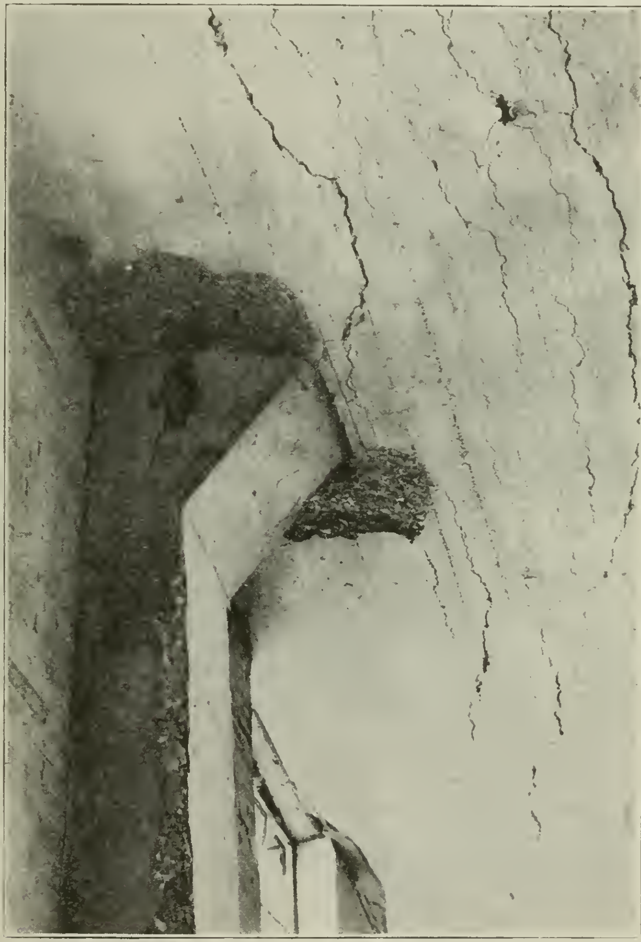

Fig. 23. Wall Slab at Bracket Head, showing Lack of Support at That Point.

this building remained to be photographed. Figure 12 shows the tangled heaps of machinery in the Mill, and part of the concrete Warehouse can be seen in the background. So intense was the fire that not even a single charred stick of wood could be found. Figure 13 gives a general view of what remains of the concrete Warehouse.

The comparatively good condition of both the hollow and solid metal sash may be seen, although the wired glass is gone.

As was shown on Plate I, most of the concrete building north of its center line collapsed, and Fig. 14 gives a view taken from near the south section looking towards the standing one and one-third bays to the north. Portions of the floor slabs hanging by their reinforcing rods are plainly visible. A closer view of the wreckage is given in Fig. 15. Near the left edge of this figure will be noticed one of the lower story columns around which may be seen the circular hooping.

EFFECTS OF THE FIRE ON THE CONCRETE BUILDING

That the concrete building became such a wreck is something that may cast grave doubts upon the fire-resisting qualities of flat slab construction. Six and two-thirds bays out of fourteen have fallen in an almost shapeless heap of debris. The cement in the floors of the parts still standing is dehydrated completely through, and when a block of the floor slab, such as may be seen hanging from the reinforcing rods is detached, it may be broken easily by dropping it on the ground or rapping it against another such block. As may be seen in Figs. 16. 17 and 22, the floor slabs practically everywhere sag somewhat, and in many places are at the point of incipient failure.

If we consider the effect of heat upon the concrete it may shed some light on the subject. Experiments upon the heat conductivity of concrete are rather few, but from those of Professor Ira H. Woolson, reported in the Proc. Am. Soc. Test. Mat. Vol. VII, 1907, p. 408, we learn that when subjected to a temperature of 1,500 deg. F. for two hours, a point 2 inches from the exposed surface of a block of concrete had its temperature raised between 500 and 700 deg. F. We learn also that dehydration of the cement crystals begins at about 500 deg. F., and is complete at about 900 deg. F. Thus we may reason that dehydration has reached a point 2 inches below the surface of a piece of concrete after being subjected to a temperature of 1,500 deg. F. for two hours. In the reinforced concrete warehouse under consideration, we had a temperature that according to those who saw it "was like a blast furnace by 1 o'clock," and which at the time of the collapse, at 6:00 p. m., had lasted five hours. We have seen that it must have reached 2,300 deg. F., and owing to the great quantity of fuel, this temperature must have been maintained practically constantly. The fact that the floor slabs are completely dehydrated is, therefore, not beyond comprehension, nor does it contradict the evidence of the experiments quoted.

In addition to this, Professor J. B. Johnson, in his "Materials of Construction," states that the working strength of steel decreases with a rise in temperature, and that this decrease takes place at the rate of approximately 4 per cent for each 100 deg. F. increase. If we take the evidence of the brick shown in Fig. 10, which shows that a temperature of over 2,000 deg. F. penetrated two inches into

a material of just about the same conductivity as concrete, and from this assume that the slab rods reached that temperature, it is evident that their working strength was reduced by about 80 per cent. For steel with an elastic limit of 45,000 lbs. per square inch, this would mean that the available working strength was less than 9,000 lbs. per square inch. In the columns this would not be of such grave importance as in the floor slabs, but in the slabs the stresses developed were in excess of this reduced allowable stress, as will be shown later. It is, therefore, probable that owing both to the weakening of the concrete in compression and the steel in tension, the floors failed first and carried the columns with them. Whether any

Fig. 24. Portion of Fifth Floor, showing Effect of Explosion in Story Below.

other type of construction would have stood the fire better is, of course, a matter of conjecture, but the weigh scale roof to the west of the Elevator was of beam and slab construction and was completely wrecked.

DETAILS OF DAMAGE TO CONCRETE BUILDING

As mentioned above, blocks of the concrete may be readily broken. At a depth of about an inch the aggregate thus exposed shows no noticeable effect, unless it be of some coarsely crystalline structure, such as granite. One such piece of granite as big as a man's fist was easily crushed by the grip of one hand. Closer to the surface the aggregate was calcined. The surfaces directly in contact with the fire were everywhere calcined from ¼ to ½-inch,

and on those blocks which fell into the fire in the collapsed portion calcination of the aggregate is practically complete.

In his investigation of the action of concrete with a quartz gravel aggregate when subjected to fire, Professor Woolson found that such aggregate caused disintegration of the concrete. In this fire, however, the damage to the concrete is scarcely traceable to the aggregate, for although it is calcined near the surface, it is neither calcined nor split at a depth of more than an inch from the surface, even in those portions of the floor slabs that are at the point of incipient failure. The cement in such places, however, possesses but little more strength than dried blue clay. Several samples of the concrete were brought to Toronto and two blocks taken from a lower floor slab where it showed least damage had a compressive strength of only 1,500 lbs. per square inch, while other samples crumbled to pieces in transit. In none of them was the aggregate affected at any distance from the surface, so it would seem that the damage to the concrete is largely due to dehydration of the cement.

In Fig. 16, near the upper right-hand corner, the aggregate can be seen exposed. In the third story this condition prevails over practically the entire ceiling, and patches of the smooth surface on all ceilings are constantly dropping off. This condition is due to the calcination of the gravel at the surface, which allowed it to fall to its own weight. In other cases that part of the slab around the column head had fallen out to a considerable depth, which was more than likely due to the compressive stress that existed in this locality.

At no point is there any evidence of fusion of the aggregate in the concrete. Particular care was exercised in verifying this fact, for in the fire at the Edison Phonograph Works at West Orange, N. J., in 1914, such fusion occurred. At first glance the material hanging from the cracks in the ceiling, shown in Fig. 17, might be taken for fused concrete, but it was found to be a phosphatic glass from Quaker Oats, which was piled in cases on the floor above.

Chemical analysis of this phosphatic glass shows the presence of the following elements: iron, silica, calcium, magnesium, sodium, potassium, phosphorus and chlorine. Silica was present to the extent of 3¼ per cent, and P_2O_5 to the extent of 15 per cent, which would indicate that the material is probably fused ash of the oats. In the exact center of Fig. 15 the head of one of the basement columns may be seen, and it looks as though fusion had occurred at this point. Upon careful examination no fusion was evident, but the large calcined mass was rapidly air-slaking.

All floors had been given a one-inch wearing surface, and practically everywhere throughout the standing portion of the building this one-inch surface had left the main slab. The ash from the burning box shooks protected some parts of the floor surface during the fiercest part of the heat, and although the wearing surface did not leave the floor slabs so noticeably under the box shooks, it is

nevertheless calcined and can be readily separated from the rest of the floor by tapping with a hammer.

The reinforcing rods, even though protected in some cases with a very thin coat of concrete, were not oxidized until exposed. This might have been inferred from the fact that a thin coat of cement mortar will prevent rust, which is somewhat analagous to the black oxide formed on metal when subjected to fire; and whereever a slab failure occurred the broken ends of the rods were drawn down as in any typical tension failure. It is thus shown that although the bond between the concrete and the reinforcing rods may have been materially weakened, it was not in any sense the cause of the failure.

Fig. 25. Effects of Small Explosions on First Floor. Note also Condition of Fire Doors.

Curiously enough, the shape and appearance of all columns seem to have been little affected, in comparison with the damage they sustained, for neither on the round, square nor octagonal ones was there much spalling. But with the exception of a few columns in the south end of the basement where there was little combustible material, the appearance is very deceptive. When struck they give out a sound like that produced when an empty box is struck, and on all columns a few light blows of a hammer will detach large pieces of concrete outside the hooping as shown in Fig. 18. There seems to be a distinct separation or surface of cleavage at the enclosing hoops.

The dehydration of the cement has affected the columns as well as the floor slabs, and extends to well inside the circular hoop-

ing. An attempt was made to determine how far the dehydration extended and a column in the top story was chosen, as sound in appearance as any to be found. A few blows with a hammer knocked the side out, as shown in Fig. 19. The surface enclosed by the reinforcing looked as though the concrete beneath was dehydrated, so two spirals were cut off and a start made on cutting one of the longitudinal ¾ in. rods. When the hack saw had cut about two-thirds of the distance through, the rod pulled apart with a vigorous snap, letting the saw slip through the remainder of the distance. A pencil is shown in Fig. 19 in the cut referred to. This would indicate that the standing portion of the building is now under a stress of unknown intensity, and it was deemed wise to dig no farther into the column.

The spiral hooping for the two upper stories was made on the the job, and it will be noticed that in the column shown in Fig. 20 this hooping enclosed a comparatively small proportion of the concrete. It did not therefore exert to the full its proper function of restraining the concrete enclosed within it. The result is that it was more of a detriment than a help to the column, forming a surface along which the concrete split in adjusting itself to the sag in the slab. From a comparison of this view with Fig. 18 it may seem reasonable to assume that the circular reinforcing of the columns was largely responsible for their standing when the concrete was so badly weakened.

Figure 21 was taken to show the protective effect of the coat of grout given to the interior columns in the third and fourth stories. The columns beneath this coating appeared more sound than the others, but after the experience on the sixth floor the cutting was carried no farther.

EFFECT OF DESIGN AND LOADING ON FAILURE

If computations are made under any of the more well known City Building Ordinances to determine the permissible live load on the various floors, it will be seen that the allowable load varies greatly, depending upon the critical points in the design. The diagonal bands have an excessive strength and the straight bands are somewhat deficient in steel, but the weakest point in the design is in the column head areas. Owing to the fact that in the lower floors the slab is the same thickness throughout, the resisting moment of both steel and concrete over the column heads is quite inadequate for the design load. This is more apparent in the wall panels than in the interior panels, and the effect is probably heightened owing to the fact that the building is but three panels wide. As these four floors were built before the laws governing flat slabs had been investigated to any extent, this need not be regarded as a reflection on the designer, for the class of work was excellent.

The fifth floor, owing to its increase in thickness, and the method by which this was accomplished, does not lend itself to computation. The sixth floor and roof represent the more modern methods of

flat slab construction, with the exception of the facts that no drop heads were provided around the wall column caps where they were probably most needed, and that the brackets provided on the columns were in no way reinforced. For shear, these brackets were sufficient, but they were very lacking in providing resistance to bending moments. Other than this, the class of work on the two upper stories was good.

The values as computed above would in all probability have proved very low, had a test to destruction been carried out, for all extensometer tests show stresses very much less than the computed stresses. But the computed allowable loads illustrate the porportional strength and lack of balance of the various parts of the design,

Fig. 26. One-half of an Elevator Shaft Door. Only the Metal Remains. The Other Half has Entirely Disappeared.

and it is probable that the design load of 200 lbs. per sq. ft. would in many places have stressed the steel nearly to its elastic limit and the concrete to a point beyond which it would not be safe to go.

From the location of the elevator shaft, the workmen found it very much easier to begin their loading from the north end of the building, and to fill both side aisles, reserving a trucking space down the centre of the building. This method of procedure naturally put the bulk of the load on the side panels where the structure was least able to carry it.

Plate I shows the occupancy of the building. In the sixth floor the sacked Vim feed was piled 13 sacks high, each sack weighing 70 lbs., over the whole area north of the elevator shaft. Therefore there was a load of over 175 lbs. to the sq. ft. The fifth floor load-

ing, Quaker Oats in cases, was comparatively light. On the third and fourth floors, occupied for the Package Department storage, there were no great loads except in a few bays in which were rolls of paper, giving a load of about 240 lbs. per sq. ft. The second floor was probably the most heavily loaded, for here sacks of hulled oats and flour weighing 98 lbs. each were piled 13 high, and sacks of rolled oats weighing 90 lbs. each were piled 11 high. This load of about 260 to 350 lbs. per sq. ft. occupied most of the floor with the exception of a trucking space down the centre. The first floor, occupied by the Shipping Department, had practically the same loading as the second floor. In the south half of the basement were some cases of dishes and some bales of scrap paper, but in the north end was a large quantity of sacked oat hulls. While this material added no weight to the floors, the ground oat hulls in burning must have helped to weaken the first floor. We may therefore conclude that the whole building was weak in the wall panel design, as well as near the interior column heads of the first four floors, and that at the time of the fire was loaded to full capacity on all floors but the fifth. That the excessive sagging is confined entirely to the wall panels is therefore not at all surprising, nor is it any wonder that in areas of excessive compressive stress the concrete has fallen. The interior panels all sag somewhat, but as may be seen in Fig. 22 the deflection in them is not comparable to that in the wall panels. The criticism of the bracket heads on the wall columns is justified by Figs. 22 and 23, where the lack of support to the floor slab is shown so plainly.

In his testimony before the Provincial Fire Marshal, one witness stated that the collapse of the building was immediately preceded by a tremendous explosion. Inquiry was made of a number of persons who were at the fire when the collapse occurred, and they are unanimous in declaring that no such explosion took place. Naturally in heaps of combustible material burning on the outside, gases would be formed within the pile and slight explosions might thus occur. The fact that they did occur is evidenced by Fig. 24 which shows a portion of the fifth floor. None of the material which came from this destroyed portion of the floor could be found on the fourth floor, but, as may be seen on the Figure it was lifted up and deposited around the opening. This is evidence of a slight explosion from below. Beneath the first floor there were one or two similar puffs as may be seen on Fig. 25.

The fact that there could not have been any explosion of magnitude may be drawn from a consideration of Fig. 14, which shows that the building apparently settled straight downward; for on the right hand side of this view may be seen a number of columns which have apparently dropped directly down. In the same view as much of the brickwork appears to have fallen inward as fell out. The condition of the concrete is in itself sufficient explanation of the failure. It is possible that what the witness heard was the collapse of one of the floors, which brought the others down.

As to some of the details of construction, the solid metal fire doors seen in Fig. 24 stood the heat much better than the wood-tin-clad doors shown in Fig. 25, when subjected to about the same heat conditions, and the trap doors in the stairway are complete ruins. The half-door to the elevator shaft shown in Fig. 26 is a mere shell of oxidized metal, the wooden core being completely burned out, and the other half of the door is nowhere to be found. From this we may reach the conclusion that the solid metal fire doors offer a more effective resistance to fire than do the wood-tin-clad ones, and also that trap doors can never take the place of a proper stair enclosure.

Early in the fire the wired glass was completely gone, and may be found hanging in sheets down the outside of the walls as shown in Fig. 8, or running down the brick inside. It must have kept the fire out of the concrete Warehouse for a time, for the first fire to gain admittance did so through an open window near the north end of the building; but this was quickly followed by fire in many places due to heat radiated through the glass. So while the wired glass made a very creditable showing under the extreme conditions to which it was subjected, it is not to be regarded as a universal panacea for exposure. It is possible that iron or wood-tin-clad shutters, if they had been in working order, would have afforded much better protection; for even if they were not of the automatic closing type, the employees had time enough to close them by hand, as they did the openings in the wired glass windows. The metal window sash and frames withstood the heat very well, as may be seen from Fig. 13, which shows both the solid and hollow metal types. The wooden frames were of course quickly consumed and the plain glass was worthless.

CONCLUSION

The first lesson to be drawn from this conflagration is that it is not to the discredit of flat slab construction that a building of this type failed under such extraordinary circumstances, for if heat is sufficiently intense and long enduring no material or type of construction can withstand it. That laboratory conditions of heat producing are not essential, and that sufficient heat can be generated by the burning contents of a building to destroy practically any of the materials of "fireproof" construction, with the possible exception of concrete, has been demonstrated in fires time and time again. The fact that concrete stood so well in the Edison fire of 1914 has been hailed far and wide, and the intensity of that fire was so great that it is generally regarded as the acme of fire intensity. It is therefore implicitly assumed that if a concrete building fails during a fire the fault must lie either in the design, aggregate used, workmanship, or type of construction, but that, in the intensity of the fire itself, the cause might be found, seems never to be considered.

That the design had something to do with the failure, under the existing conditions of loading, has already been shown. The

workmanship was good and the aggregate not affected deeply enough in the slab to have caused the failure, although both have been ascribed as the cause. (See Canadian Engineer of Mar. 1, 1917, page 197.) The writer, however, cannot agree with this. The failure, then, must have been due either to the type of construction or to the intensity and length of duration of the fire.

It seems almost sacrilege to say that at the Quaker Oats plant there was a much more severe fire than at the Edison plant. Yet cuts were printed in the press at the time of the Edison fire which showed that in not one of the large concrete buildings were all the floors in full blaze at the same time, nor did the fire remain in full intensity for more than an hour or two at any one place. Neither are there more abundant proofs of intense heat. In the concrete Warehouse at the Quaker Oats plant, however, fire of an intensity at least equal to that developed in the Edison fire occurred on all floors at the same time, and it was seven hours after the fire started before the collapse occurred. In the standing portion of the building the fire burned for several days, and even after two months' time there was considerable heat and fire in the collapsed portion. There was no fusion of the concrete, but this is due to the fact that limestone was used as an aggregate, which does not fuse, whereas in the Edison fire a variety of trap rock that fused at about 2,000 deg. F. was used.

We may safely state that this building succumbed to the fire, not because of the type of construction, but because of the extreme intensity and duration of the fire, which raised the 9 in. slabs to a degree of heat sufficient to destroy the crystal form of the cement in the concrete and to reduce the strength of the reinforcing rods to practically nothing. Had the Edison buildings been subjected to anything like capacity loading and fire of three or four days duration, they would in all probability have fared no better than did the Quaker Oats Warehouse.

In the recent controversy over the recommendations of the Joint Committee on Flat Slab regulations both sides seemed to have overlooked the effect of fire on the structures. All extensometer tests show that the stresses developed by a given load are less than the computed stresses, and this fact is variously assigned to "dome action," "slab action" and "tension resisted by concrete." This fire brings forcibly to mind that it is possible for all these factors to be eliminated in an existing structure, and undue dependence should therefore not be placed upon them.

As to the question of the amount of fire proofing required, the complete dehydration of the floor slabs proves that it is possible to raise the temperature of a 9 in. slab to 1,250 deg. F. completely through. This would show that it is possible to reduce the strength of the steel by about 50 per cent, even if placed 4½ in. from the surface. The depth of calcination of the aggregate shows that a temperature of 2,000 deg. F. was reached at a point more than an inch from the surface. These facts show that it is impossible to

afford absolute fire protection to the reinforcement and do so economically.

The last point to which attention should be directed is that it is downrightly wrong to claim that structures of this or that type of construction or material are fireproof. There is no such thing. Yet there are those who are deliberately misleading prospective clients into the belief that concrete construction is absolutely fireproof. Because of this fire concrete construction needs no apology, neither does flat slab construction; and those for whom buildings are erected will not lose faith in the engineering profession half as quickly when told frankly that the term "fireproof" is merely a relative term as they will when a type of building which they have been led to regard as absolutely fireproof fails when put to the test. Lest these last remarks be misinterpreted, let it be understood that they in no way refer to the engineers of the concrete building at the Quaker Oats plant, but are applicable to engineering ethics only.

In conclusion the writer must acknowledge his indebtedness to Mr. W. W. Pearse, City Architect of Toronto, for permission to make use of the report submitted to him, and to Mr. A. J. Mylrea of the Sprinklered Risk Department of the Canadian Fire Underwriters Association for permission to use Plates I and II and for information and photographs concerning the progress of the fire.

DISCUSSION

The Chairman, *N. M. Stineman,* ASSOC. W. S. E.: Is any portion of this building to be reconstructed, or must it be entirely demolished?

Mr. Mylrea: It must be entirely demolished; there is absolutely no chance of repairing it.

S. H. Ingberg: I would like to know a little more about the details of the damage to the three concrete tanks. We have had instances where a very intense fire has damaged concrete tanks from radiated heat which has been attributed to the concrete aggregates employed.

Mr. Mylrea: There is very little damage to them at all. The lower 15 feet was buried in burning grain and the heat there was terrific. Above this height the direction of the wind prevented much damage; but where the fire was applied directly to the concrete there was considerable spalling, and in some spots this spalling extended entirely through the shell. Other than this there was no damage.

The Chairman: In the winter of 1915-1916, Elevator K, in Minneapolis, owned by the C. M. & St. P. Railway, was destroyed by fire. It was an old frame elevator, and stood within about twenty-five feet of some reinforced concrete grain tanks. The tanks were not damaged at all, nor was the temperature in the tanks raised to any appreciable extent. However, those tanks had an in-

side wall of about 6 inches, an air space, and an outer shell. The fire lasted about five hours, and the tanks were completely enveloped in flames for about three hours.

W. C. Robinson, M. W. S. E.: In the designing of buildings, you must not give your entire attention to the designing of your structure as a load bearing structure. Had the plan in question been designed to segregate fire,—of course, this is an unusual case, starting by an explosion and it is pretty hard to provide against that,—but so far as the reinforced concrete buildings are concerned, it would have been perfectly possible to have provided against their destruction, to have kept the fire from entering these sections, and if it had entered at any one point through some mishap, from extending throughout other stories and sections as it did.

This relates, to some extent, to the designing of the building, to retard the spreading of fire, such as by the segregation of areas by fire retardants, so that the heat does not reach such tremendous volumes.

The tin-clad fire-door and the metal fire-door were mentioned in the paper. The tin-clad fire-door and the metal fire-door were shown, and the metal door was shown to be a single sheet counter-balanced elevator door. This latter type of fire-door is approved generally by the Underwriters, and is considered a first-rate fire stop, but you must remember that it should not be used on a fire wall, because of the transmission of heat. While it will stand high temperatures, and you can heat it, if properly designed, to very much above red heat, pretty near white heat, yet the radiation of heat through the sheet iron, where you have only the thickness of the wall, will permit the fire to enter very much the same as the wire glass windows did in this case.

This and the fact that fireproofing buildings do not necessarily mean that the contents will be protected, are the main points I have in mind. The contents of buildings are usually combustible. If they take fire they will generate heat, the amount of heat depending very largely on the volume and nature of the contents. This possibility of exposure should be taken into consideration, as a factor in the designing of ,the building, as the speaker stated.

In discussions or controversies covering reinforced concrete construction, like most discussions on a subject of that sort, a very important factor usually is ignored, and that is the question of fire exposure. It is the hope of our institution that this factor will be brought more prominently to the attention of the engineering fraternity and thus perhaps furnish some valuable aid in supplying additional information.

I did not intend to make mention of all the various points, but only the three thoughts—the designing of the building itself; the fire door question; and the contents question—were prominent in my mind, as the paper was delivered.

F. W. Fredericks: In looking at some of the pictures shown this evening, one of the things that seemed to impress one was the

fact that a maximum temperature of 2,300 deg. reached by the conflagration, seems to be a rather conservative one. While cast iron will not decarbonize and lose its tensile strength as rapidly as steel, a temperature of 2,300 deg. F. appears to be all right for the melting point of cast iron but not for structural steel. It strikes me that possibly 2,700 deg. would better represent some of the higher temperatures reached.

Mr. Mylrea: That was given as a very conservative estimate.

Mr. Ingberg: On that first point, we have a clear instance of the melting of the structural steel in the fire. There have been cases where the sheet metal has apparently been burned through. Of course, it might have been a matter of oxidation only, instead of melting, but in the case of the steel column, it must have been a case of fusion.

Can the speaker give any further information as to the contents and other special conditions that would give rise to the high temperature in that particular case?

Mr. Mylrea: As far as the 2,300 deg. F. is concerned, I said *at least* 2,300, and I preferred to be conservative.

The melting of the columns was an actual case of the structural steel fusing, and as Mr. Fredericks has pointed out, the temperature, in that particular case at least, was probably nearer 2,700 deg. F. than 2,300. The building in which the steel melted was the Dry House, where the fire started. On the fifth floor of this building there were some seventy or more tanks five feet in diameter and twenty-one feet in height, containing a large quantity of ground material for mixing and making feed; when the spouts from the bottoms of these tanks were broken off, this ground material sprayed out and burned with an intensely hot flame. Witnesses stated that it seemed as if many immense gas torches were blowing down into the building, and this may account for the high temperature developed.

Mr. Robinson: In that high temperature question the speaker was probably conservative in giving 2,300 deg. Some of this concrete was perhaps subjected to that temperature, but it is well known that you are apt to have an intensification of fire in places.

A number of years ago, after a fire in the Parker Building, New York, we found some places where there was incipient fusion in copper, which is at about 1,900 deg. and in a number of places we found fused cast iron parts. The temperatures in several stories melted small copper wires and brasses very readily, and I should judge by this whole fire that the temperatures were in many places very much more than that, and probably they were even higher than 2,700 deg., judging from what study I have made of the fire.

Mr. Mylrea: To illustrate the protective effect of concrete, this piece of reinforcement was within one-half inch of the surface of the concrete at a point where the heat was probably as intense as at any other place, but it is absolutely undamaged. This second specimen, taken from the same rod, less than a foot away, but

where the sagging and cracking of the floor had exposed it to the direct action of the flames, was badly oxidized, as may be seen.

I had two or three blocks of concrete which I had hoped to be able to bring with me, but in the time which has elapsed since the fire they have all crumbled to pieces. However, I managed to preserve this piece of slab topping coat, and it has about the same strength as cheese.

Mr. Robinson: Is that a mortar top?

Mr. Mylrea: Yes, it is the regular mortar coating.

Mr. Robinson: That seemed to have protected the slabs on the two top floors?

Mr. Mylrea: Yes, it did to a certain extent.

Mr. Robinson: And the mortar, between the bricks?

Mr. Mylrea: That is a very peculiar point. It stood up, although the sand in the mortar was partly calcined, and the bricks melted. A month or two afterwards, air slacking caused the mortar joints to break down, and the glazed brick is peeling off.

W. M. Kinney, M. W. S. E.: The manner in which the mortar joints stand out from the brick suggests the use of cement mortar for a plaster coat on limestone concrete columns as a further protection against such severe fires.

The method in which the concrete spalled from the columns reinforced with band steel spirals also raises the question as to whether the use of bands or flats for spiral reinforcement is good practice. In fact a few tests made by D. A. Abrams at the University of Illinois* would indicate that there is a limit beyond which it is undesirable to go in reducing the ratio of thickness to width in such shapes used for reinforcing. For unit cross-sectional area, bond resistance is assumed to increase as the circumferential area increases, but apparently this does not hold when the section becomes too thin. Certainly spalling is more liable to occur and it would seem far better to use a round section for such spirals and in the reinforcing for circular tanks for which flats and bands have been widely recommended. A long plane of flat steel invites spalling under extreme temperatures.

James N. Hatch, M. W. S. E.: One of the pictures brings to mind a rather alarming condition that I once found in examining a furnace lining for a boiler. The foundation of the boiler had been built of concrete, and where this concrete came near the furnace, it was protected by four inches of fire brick. After the furnace had been in operation for some time, it was necessary to take out the fire brick and change the lining.

When the lining was taken out, I had occasion to examine the concrete behind the brick lining, and I was surprized to find that this concrete for several inches in depth was absolutely destroyed, so far as having any strength.

The cement seemed to have been entirely destroyed and the

*Bulletin No. 71, University of Illinois Engineering Experiment Station, "Tests of Bond Between Concrete and Steel," by D. A. Abrams. Page 48-49.

sand and broken stone could be taken out in handfuls as clean as when they were put into the mixture.

This was rather a startling condition, for it had been supposed that the four inch brick lining would protect the concrete, but it was found that it was possible to get heat enough through this four inch brick lining to ruin the concrete behind.

O. F. Dalstrom, M. W. S. E.: What constituted the combustible material that produced such intense heat in this fire? Was it attributed to the grain and grain dust throughout the building?

Mr. Mylrea: On the sixth floor and on the first and second floors it was due entirely to the great quantities of grain piled up there, both in the ground and unground condition. Sacks of flour and sacks of oats were piled right up to the ceiling, and they burned with all the intensity of coke—smokeless, but with great heat of long duration.

On the third and fourth floors, box shooks were piled practically to the ceiling, too. These box shooks were simply collapsed boxes which could be assembled and filled with goods for shipment. So what we had was really a half inch of wood and a half inch of air space, from floor to ceiling, and it was clean dry spruce. You can imagine what heat this might generate.

J. W. Lowell, Jr., ASSOC. W. S. E.: Small industrial fires occurring every day pass unnoticed and only the holocaust causes most of us to stop in our daily tasks and take notice. Therefore, it is by these great fires that we learn the real lessons of fire prevention and thus improve our engineering knowledge and better our capacity for service to mankind.

This paper has been of great interest to me, not because of the fact that the Quaker Oats Co. lost a great deal of business, not because some insurance company lost many thousands of dollars, but because men of our profession failed in their service to their employers and to mankind. By making this statement, I do not mean to cast discredit on any person, not to criticize them because ignorance of fire prevention engineering is general throughout the profession, and is not considered vital enough to be taught in our colleges. I do feel that our profession must concern itself in the future with the engineering fire prevention and protection.

To begin with, engineering students should be taught the theory and practical application of this subject. We who are practicing will be benefited greatly by lectures such as the one which we have just heard and others presenting various phases of the subject. Whenever we are called upon to design buildings and groups of buildings, we should bear the fire hazard in mind, as an important factor, and if we are not competent to solve the problems involved, consult with specialists.

A Member: I would like to ask a question in regard to the exposure to fire in this plant through the conveying machinery and other openings?

Mr. Mylrea: I did not go into that question to any great extent, devoting my attention principally to the effect of the fire rather than to the cause of its spread. But as I understand it, there

were only a few conveyors through the fire walls, though the openings for these were unprotected. In addition to the conveyors, there were two unprotected openings, about eighteen inches by four feet, in the firewall between Warehouses No. 1 and No. 2 through which package dryers passed. In all probability these openings were largely responsible for the rapid spread of the fire from Warehouse No. 1 to Warehouse No. 2.

There were also numerous instances of unprotected floor openings. For instance, in the concrete building there were two bag hoists, each making an opening in every floor, three feet by seven feet, without any attempt at an enclosure. In addition, there were one or two chutes from floor to floor.

In general, the protection against the horizontal spread of fire was much superior to the protection against its vertical spread.

James S. Stephens, M. W. S. E.: The layout of the water piping around this plant seems to have been entirely inadequate. From the looks of it, it seems as though about six fire streams is all this plant would afford, which would be very small supply for a building which occupies at least two city blocks.

Another point, the heat from this building was considerable above a white heat, and glass has no effect in stopping heat after it becomes an incandescent heat, which it was in this instance. The question is whether or not a Florentine glass with a refractive property of some kind would cut down this white heat radiation, or whether or not shutters should be put on there to answer that purpose.

Mr. Robinson: The comparatively low fusing point of glass prevents the use of any kind of glass for anything more than what we term a moderate exposure. The transmission of such a fire as has been described to us, through wire glass windows at that distance, was only a question of time. In this city I have seen a fire take place on the wooden running boards of fringe machines sixty inches back from a wire glass window without materially injuring the windows. We rate such retardants as only good against moderate fire exposure. In a plant where such conditions as this existed they should have had two forms of protection; that is, some other form of fire retardant at the windows, which would have resisted the extreme temperatures possible from the burning mill building.

Mr. Ingberg: Building ordinances and standards of design must necessarily be based on ordinary, rather than extraordinary, conditions, as otherwise we would have them loaded down with such excessive requirements that they would interfere with the legitimate development of the industries. I think it emphasizes the necessity for investigating the fire-resisting qualities of building materials and also the exercise of considerable judgment on the part of the designer in using the materials in the proper manner, considering the conditions of exposure and hazard to which the structures may be subjected.

While in this fire there are indications of very high temper-

atures of long duration, it does not follow that we should try to design all fireproof buildings for these very excessive conditions because we are quite justified in saying that they obtain only in a very few fires.

CLOSURE

Through the courtesy of the Quaker Oats Company and the Leonard Construction Company officials, the writer was enabled to make an examination of the condition of the columns while the standing portion of the building was being razed. The strength of the interior columns in the upper stories was greatly reduced owing to the fact that dehydration had extended practically through them. Naturally, the nearer the center of the column the stronger the concrete, as nearer the center the dehydration was only partial, but it was an easy matter to break the columns to pieces with mauls.

On account of their greater thickness, the lower story columns were more sound at the center than those of the upper stories, but as the foreman in charge of razing operations said on picking up a piece of the concrete: "It's easy to see the cement is dead." The outer nine inches of the wall columns was protected by the brick walls, and the contrast was very marked between the portion thus protected and the portion which was directly exposed to the fire. Unfortunately, it was impossible to secure a piece large enough for testing.

In his last remarks Mr. Ingberg corroborates the writer's statement that "It is impossible to afford absolute fire protection to the reinforcement and to do so economically," and he draws the very sound conclusion that it would be folly to attempt to make buildings absolutely fireproof. If there were no other alternative it would be more economical to permit the occasional destruction of a building by fire than to force the expense of construction to a prohibitive figure.

The Edison fire proves that a concrete structure can resist a great fire, but the Quaker Oats fire proves that it is possible for fire to develop sufficient intensity to destroy such a structure. The logical thing to do, therefore, is to fight the fire before it starts—to put it out before it reaches serious proportions or to prevent its spread. It has been the fashion to regard this as the province of the fire protection engineer or of that hateful being who raises insurance rates, structural engineers and architects confining their attention to mere strength or effects. But it is a cause for satisfaction that they are beginning to realize the need of considering the possible effects of fire in making their layouts, and it is to be hoped that the practice becomes more general.

It is a question, of course, whether any combination of fire prevention devices could have withstood such an extremely unusual combination of circumstances as that to which the Quaker Oats plant was subjected; but in their new layout the engineers have endeavored to circumvent such a contingency. However, "That is part of another tale."

October, 1917

AMERICAN RESEARCH METHODS

By Charles H. McDowell*
Presented April 16, 1917

The American has always prided himself on being practical. His pioneering ancestry had to be. They were a long ways from a machine shop, and were long on acres and short on labor. Necessity forced invention and labor-saving machinery applicable to the task on hand was speedily developed. They had little technical education and less use for it. They questioned the soundness of the professorial type. Manufacture was based on cheap raw material and there was little necessity for close working. People could waste their timber, strip their coal mines and rob their fertile farms and get away with it, and few knew they were committing an economic crime for which penalty must be enacted later. The transportation problem was tackled and solved. The rather loose sort of manufacturing, coupled up with ingenious labor-saving machinery and with the natural organizing ability of those in charge of industry, rapidly developed our manufacturing and mining as far as output, standardization, shop system, etc., was concerned. In conformity with our natural disposition for directness and quick results, our development along mechanical and electrical engineering lines has been unusual, but until recently there has been a lack of appreciation on the part of the manufacturers of the importance of chemistry and chemical engineering in practically all lines of manufacturing, and it is only lately that the value of research laboratories has been realized. Some of the larger corporations have now installed them, and in one instance an industrial research laboratory for the benefit of the members of an association has been organized.

One of the peculiarities of the United States has been a lack of respect for its experts. This is reflected in the attitude of many of our farmers towards the agricultural expert and in Congress toward the recommendations of our Army and Navy heads. We are fond of practical men—practical men often distrust technically trained men. Scientific men have frequently been lame in not closely co-operating with practical men and letting them know they can be practical too. Then again, technical language can be simplified and made more understandable to the average man if the importance of this is more generally appreciated by the scientifically trained man. Mutual respect should be cultivated. The Herr Professor Doctor of Germany has been believed by his people and his advice has been followed. Here the tendency has been to copper the advice of the so-called high brow.

The best results in modern research come from the work of trained investigators, although as Atcheson says, "many of the big things in invention have been discovered by the d—d fool who

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*President Armour Fertilizer Company.

didn't know any better." And this idea is quite prevalent in the minds of the laymen.

There is such a thing as over education and a too implicit trust in text books and known reactions. Reference books are largely compilations and original error is sometimes perpetuated. I recall a case where a heading in one of Lunge's acid tables was transposed by a careless student working for Lunge in Germany in the '60s, and this error occurs in every edition of the book and in all languages. We were doing some work where the results contradicted the figures given and reference to the original German year book containing the original work showed up the error. No one can tell how much damage this error may have caused investigators since that time.

The fact is also overlooked that we are now able to maintain temperatures and pressures that a few years ago were unobtainable, and many things can now be accomplished that formerly were thought impossible. A study of old failures as shown by the literature of forty years ago might often prove of value in the light of modern developments.

It has been my good fortune for the past twenty years to be more or less closely identified with the development of the by-product packing-house industry and to direct a very considerable research not only in packing-house lines but in channels which had to do with the development of materials and machinery used in the manufacture of fertilizers and other chemicals. In this work, I have had associated with me a number of chemical, electrical and mechanical engineers. The first important problem naturally was to develop to the fullest extent by-product values and to utilize material which under the old order was largely thrown away or, if saved, was of little value. To accomplish results in this line of work it has been necessary to do general research to ascertain what the material contains; what use was being made of it in other countries; the demand for possible products, if made; whether it would pay commercially to make these products in this country; and whether new products could not be developed and a demand created for them. Much has been accomplished along these lines.

The definition of research is "diligent inquiry," and, if results are to be obtained, diligent inquiry is necessary; infinite patience is required. The reason for failures must be ascertained. One must learn to stand punishment; to wait; to act quickly; to differentiate between the unimportant and the worth while; and above all one must have good backing. Research chemists are often lacking in the ability to apply practically the results of their work and a different type of man is often required for the second or small manufacturing stage. Frequently, things work well on a small scale and failure results when mass action comes into effect. Often the reverse is true. A third type of man frequently is required when the commercial manufacturing scale is to be carried out. All of this means team work. It means not only laboratory equip-

ment but small manufacturing equipment. In our work, we maintain a manufacturing laboratory consisting of small manufacturing units where various processes can be carried out on a manufacturing scale. This equipment consists of mills, electrical and other furnaces, pressure tanks, vacuum pans, filter presses, dryers and other machinery used in standard work, so that a process developed in the laboratory can be tried out on a small commercial scale. This laboratory has been a source of some profit to us in various lines, due to the present conditions and to the scarcity of many articles formerly supplied from the other side. It is our idea to as far as possible make our research work self-supporting. The General Electrical Company has been successful along these lines. We also maintain fellowships in the Mellen Institute where research development can be carried on away from our packing-houses and fertilizer plants.

My observation is that people do not do things until they have to but that there are great latent powers in men when necessity calls for them. Since the beginning of the war this necessity has arisen and our people are responding to the call. The organization of the Naval Advisory Board was one of the first important recognitions by the civilian side of the Government of the power and usefulness of technically trained men in solving the problems which were confronting the people. The work of Herbert Hoover, of the Belgian Relief, and his thirty-four American engineer associates has shown also the power of efficient work possessed by our technically trained men when given the opportunity. The public does not know that Mr. Hoover's chief assistants were all technically educated men, accustomed to frontier conditions—able through their training and experience to quickly co-ordinate their energies to the work in hand. This work is a great tribute to the output of the highly trained, educated mind.

The appointment of the National Council of Defense consisting in part of men expert in different lines of endeavor is another manifestation of the awakening interest of our civilian Government in the possibilities for help from this direction.

A short time ago at the request of President Wilson a National Research Council was appointed by the National Academy of Sciences to co-ordinate the scientific research of the country, in order to secure efficiency in the solution of the problems of war and peace. However, no funds were provided and the members had to defray all their own expense of attending the meetings.

A private organization, the Engineering Foundation, which was established to further scientific and engineering research, came to the rescue and placed all their financial resources and their secretary at the council's disposal, making it possible for the business of the nation to proceed. This one incident is really typical of the actual conditions in both private and public research in the United States.

A recent article in one of the technical journals states that a rough survey of the technical journals reveals that of the original

articles contributed 50 per cent were of German origin, 16.3 of French origin, 12.2 of English origin, 6.6 of United States origin, 5.3 of Russian origin, 4.9 of Italian origin and .7 of Japanese. While it may safely be assumed that only a small proportion of the actual research results of this country are published, there must be some definite tendency or reason why a country of such industrial activity and initiative as this should only publish one-eighth as many articles of original research as Germany.

One excuse that has been offered for the present and past conditions governing research in America is that the American mind is not one of research but of action. It is true that the average American business man is not as a rule looking far ahead for future development, but demands immediate results to meet or overcome existing competition. Neither is he willing to back an experiment which costs money to fail; his slogan is, "Be sure your experiments will be successful, or don't start them." He is also loath to allow the publication of research results, fearing his competitors may gain some benefit therefrom.

In this connection, the General Committee on Research for the American Association for the Advancement of Science has recently issued an appeal to the industrial research laboratories of the country urging them to publish more of their results, particularly physical and chemical constants. For a time these might be of considerable commercial value, but they would soon be only of scientific interest, and when there is so much research to be done and so little time and such few facilities it seems almost criminal to have to waste time in redetermining constants of only scientific value. Certain industries are classed as sponges, all too eager to absorb any information from scientific literature but never giving anything in return.

The American business man is not as a rule inclined to change old established processes for new untried ones, even if they are theoretically the better; nor is he inclined to cast out a perfectly good machine simply because a newer type is capable of doing the same work with a little more economy. Some of our most successful men are refreshing exceptions to the rule. Carnegie once said that he had made more money out of his scrap heap than out of any one other thing. He was not afraid to scrap expensive machinery or an established process if a better or even a more promising machine or process was brought to his attention. The U. S. Steel Corporation has spent over $800,000 in research on the electrothermic production of steel, and the problem is still unsolved.

There are three main types of research:

1. Pure scientific inquiry.
2. Industrial research laboratories.
3. Factory research.

In the first of these the investigator is usually in search of knowledge, and has no thought whether the results of his labor

will be of commercial importance or of benefit to mankind. He is often a university professor whose main duty is teaching and who puts in his extra time following up research problems. Often these men have little commercial instinct and overlook the practical side of any discovery they may make. To be able to weigh an atom might in their estimation be of more interest than to cut ten per cent off the cost of steel. Many valuable commercial developments have resulted from pure scientific research.

In the second type may be classed all research which has some betterment of commercial practice as its goal. It may be accomplished in test tubes in the form of making a new dye or it may require the reproduction of an entire manufacturing plant on a miniature scale to expand theory into practice on a large enough basis to warrant the construction of a full-sized plant. The larger manufacturer maintains his own staff and equipment to carry out investigations along any line that may seem desirable, but the smaller industries are not able to support an establishment and must rely on either consulting engineers or turn their problems over to some equipped public or private laboratory to solve.

The third type, or factory research, is usually carried out by the practical factory operators on a full-sized scale, oftentimes with little or no forethought or calculation, and many are the failures in consequence. However, this is being rapidly overcome, because many of the present day factories are in charge of technical graduates who figure out every contingency that may arise and plan to offset them so that the chance of failure is many times reduced.

The United States today is vitally interested in the second type. We are largely isolated from the European countries whose research has made it possible for many of our industries to be built up. From now on we will have to depend more and more on our own resources. There is no question but what this country can be absolutely self-sustaining if all of our energies are devoted to the solving of our problem. We must look farther than the problems of war. It may be possible, by devoting all of the country's research facilities, to solve the problem of war with no great difficulty, but after the war the industrial problems will no doubt be even more complex than they are today. Without question Europe has made wonderful studies in new processes during the last two years under the stinging whip of necessity. We know practically nothing of these discoveries. Immediately after the war all European energy will be devoted to turning these new ideas to the best commercial account and the United States must be on guard to see that our own industries keep up with the procession.

A professor in one of our large universities said in conversation a few days ago, that in his opinion one of the main things lacking in the research of this country was co-operation between industries and educational institutions. In explaining his remark he referred to the custom in European countries of having the university professors also in the employ of some industry, so that the research

undertaken would be directed along lines of industrial achievements. This plan is being introduced into a number of the leading schools in this country, but only one has had sufficient experience to be classified as a success. This is the Mellon Institute of Industrial Research of the University of Pittsburgh. This was founded in 1911 by the late Robert Kennedy Duncan as the Department of Industrial Research, and in March, 1913, was placed on a solid basis by a gift of over half a million dollars by the sons of the late Judge Mellon, an alumnus of the university.

Briefly, the scope of the institute is as follows: Any one may found a fellowship in the institute for the solution of any problem that has not already been undertaken by the institute. These fellowships run from one thousand to ten thousand dollars a year, this sum representing the salary of the man or men engaged in the work. The institute furnishes all ordinary laboratory facilities and the use of all of their standard industrial equipment, but any special apparatus is to be paid for by the company. The Fellow devotes all of his energy to the problem assigned. At frequent intervals all the Fellows and Directors meet together and discuss the various problems. All discoveries or inventions belong to the company, but in addition to his salary the Fellow is given a bonus commensurate with the value of the discovery.

It would seem that this plan is a very excellent one. A company, by the expenditure of a comparatively small amount of money —say five thousand dollars per year on the average—obtains the undivided service of one or more men and the consultation services of probably thirty other men, all trained in industrial research. Also they have the use of the entire plant of the institute, which includes the resources of the university. This brings the Fellow consultation privileges with trained men in physics, engineering, biology, etc., to say nothing of the library facilities (the institute itself having chemistry as its specialty). Such physical facilities as these would cost any one company close to $75,000 per year to duplicate, and it would be practically impossible for even the largest industry to duplicate the consultative facilities available in the faculty of the university. The Institute Fellows cover all fields as a partial list published by the directors shows: Petroleum—Baking—Aluminum—Glue — Soap—Glass—Yeast—Leather—Fertilizer—Turbine Engines—Fatty Oils—Ores—Acetylene—Laundering—Dental Supply—Trade Problems—Land Development—and many others. It will be seen the subjects are mainly chemical ones, but others of any nature may be undertaken. All of the work of the institute is kept confidential, and while the various problems of all the men are openly discussed in the general meetings, all such discussions are kept confidential by all present. Quite a number of fellowships have been brought to a successful conclusion, and in many instances the Fellow has been taken into the permanent organization of the company to oversee the commercial application of his results. The plan seems sound, and seems to be one of the best ways of solving our industrial problems.

The other most typical example of co-operative research is the laboratory established in Washington, D. C., by the National Canners Association. This laboratory is supported by the entire association, and while its main object is to solve general problems affecting the entire industry, it undertakes all sorts of investigations of the canning business, its findings being at the service of any of the members. It is understood that the venture has been most successful, but only recently it was found necessary for the association to endow a research fund at one of the large eastern universities, in order to work out the question of ptomaine poisoning, so that the findings might be above suspicion of being influenced by the commercial side of the question.

We have been behind other countries in our technical results, and it is time for all technical men to consider all sides of the problem so as to meet the unusual conditions which will exist during the coming strenuous times.

As an illustration of research I have brought with me a line of products developed from an ore called Alunite, a deposit of which is located in Southern Utah. For hundreds of years impure deposits of this mineral have been worked in Europe for the manufacture of the old Roman or potash alum, then largely used as a mordant in fixing colors and for other chemical purposes. Due to the embargo on potash shipments from Germany, it was necessary for this country to develop supplies of this necessary material. This work has covered some years of careful inquiry and is one illustration of what can be accomplished in looking into the possibilities by making the most out of a material while it is in hand. A plant constructed for the making of potash has been in operation for something over a year. And while the manufacture has not been developed as yet to the extent shown by the research, serious consideration is being given to its further development.

DISCUSSION

Dr. Henry W. Nichols, M. W. S. E.: The aluminum deposits were supposed to be good for nothing until after Doctor MacDowell took hold of them. I have seen any number of reports saying that there was really nothing there, so that they perhaps went a little further than the chemical research.

But, on the general research proposition there is not very much to say as there is so very little of the research of this type that I know of being done. The larger mining companies—the copper mining companies, are doing as little of that kind of work as they are compelled to. They are taking about two per cent over and working in an unusual type of ore that has never been handled before.

I have seen through Arizona, recently, some work of this semi-factory type carried out in conjunction with the large mills something comparable with this, but outside of the mining industry

and perhaps a little in the electrical industry, I am not acquainted with any research of that type.

B. E. Wilts: I might add that I am identified with the Universal Portland Cement Company and possibly at some future date we may be able to contribute something to the potash resources of this country. Our raw material, at this time is rather devoid of large quantities of potash, but it would be possible, under certain conditions, to extract, during our calcination, some of it.

The process is under investigation, and there is a dust precipitating apparatus throughout the plant. When this is completely installed, we intend to carry on some investigation on the dust end of it, and it may be possible to develop it into something. That is, to treat this dust, possibly by calcination. The potash content is very low. The shale-limestone people are better situated than we are as they have from one and one-half per cent to two and three per cent of potash to begin with. If it is Feldspar it is better than that.

Some of the Portland cement plants in the West are extracting potash very profitably. In fact, one of the cement plants in California, I was informed, had decided that the making of cement was going to be a by-product and that the potash recovery was to be the main object of the operation of the plant.

We have not gotten to that point but, nevertheless, it may develop into something which will be worth while for us to recover, and thereby contribute somewhat to the potash recovery of this country.

W. W. De Berard, M. W. S. E.: Have you investigated any of the aluminum sulphate products in Mexico? My brother is in the water filtration business in Denver, and he made some investigation three or four years ago, and found some very fair samples of aluminum sulphate, but I presume that there is no potash connected with this, as he never reported any. He is looking after the alum end of it, and not for the potash.

Mr. MacDowell: There are some sulphate deposits in Mexico, and also in Arizona, but they have never been developed. I have seen samples of some very fair stuff, running as high as 60 percent, but there is no potash in connection with it. It is just straight alumina.

I might say, however, that there are some possibilities of getting results from cement calcination. In California they are making about 150 tons a month of 40 percent. They got into it because it was a nuisance. The cement dust scattered all over the country and ruined the orange blossoms, and they had to shut up shop if they didn't do something. So they started on it, and since then they have put in a later type method.

Very good results are being obtained from the blast furnace works. We always analyze and look into anything that is running away; it is the first thing a packing house man does, and he goes over the "tailings" to see whether there is anything in it or not. In the utilization or overcoming of these dust losses, we are working along the right line.

J. W. Mabbs, M. W. S. E.: What is the relative commercial value of the production of potash in kelp on the Pacific Coast, in relation to this mineral deposit. How does it compare in cost, and how does the potash compare in cost with the German potash?

Mr. MacDowell: There was about 50 percent production of the kelp product, which has not been very successful. Some people have been drying it and shipping it where it is used as fertilizer, and some people are making it into Potassium Chloride, and the cost of it is rather an unknown proposition. They have been unable to determine the cost of it. All of these Potash products, so far, have been taken mainly to get the potash and they have not been figured out on the "after the war" basis. Of course, we could figure it out if we wanted to put in a complete installation.

Mr. Mabbs: How does it compare, approximately?

Mr. MacDowell: On paper, we should be able to make sulphate of potash and compete with the Germans at the pre-war price, and if we can utilize the aluminum, we could compete with them afterwards. The other products will solve the problem one way or the other.

Mr. Mabbs: And bring it down into the same catalogue?

Mr. *MacDowell:* Yes, sir. We don't yet quite know, in all those things just what we can do if we were to get in a complete production and with a full installation of machinery, but now the thing is to get the potash.

Mr. Mabbs: Can you produce the potash cheaper from your process than from kelp?

Mr. MacDowell: Yes. Because we have our complete body of ore where we can get at it. We don't have to bet on the weather and upon when the kelp will grow again, or the labor conditions as they exist on the Pacific Coast. If you can secure your potash and get it into your plant and can overcome some of the technical difficulties, you can work it out. Our Japanese friends are doing it successfully, but whether they can compete after the war I do not know. Their labor conditions are such over there that they can get this kelp at much less cost than our folks out West, who work on an eight-hour union basis.

Mr. Levy: In regard to some of the questions and the figures, it is figured in round numbers that the potash cost somewhere around $60.00 a ton. Of course, we were getting potash in an equivalent form from Germany before the war at something like $39.00.

The possibilities of obtaining potash on a basis, comparable to what obtained prior to the war would not be possible, unless we could obtain iodine, acetone and possibly some other things from kelp.

Some figures have been worked out and some small plants have been erected with an idea of measuring these products and anticipating what we might expect. These figures show that it is sufficiently promising and that a plant might be erected with the

possibilities of producing potash on the market at $42.00 a ton. That does not make kelp very promising for potash alone. Now, we are obtaining a very fair or fancy figure for acetone, which is used for various things, and as a result we will have to look to something else for our potash, or re-vamp our processes of production.

What are the possibilities of obtaining alumina compounds, under present operating conditions?

Mr. MacDowell: Theoretically it takes less power. The temperature required is considerably higher. It takes 1,700 to 1,950 deg. C. The question of rafractories has been the qualifying thing and that has been the thing which has held back more than any one other thing. We have not gone at it on the larger scale, but did it because we wanted to see what the possibilities were along that line. We have not really tackled it in a way in which we really thought that we could make it commercially, but I see no special reason why it cannot be worked out. That is one of the reasons why we got into the refractory investigation. We put in a lining made out of this material that lasted for two years, and when we finally let it go to the limit, we went up to about 2,300 deg. C. We feel that we have a refractory that can stand a very high heat for certain things. We could not find a refractory that would stand up, and so we went into it ourselves.

M. L. Carr, M. W. S. E.: A great many things started originally from the pure scientist, and I think that perhaps the commercial research man of today has gotten his ideas originally from the work of the pure scientist.

We must remember that the Roentgen Ray, which is used today very largely in a commercial way, was the result, originally, of the work of a man who was studying science purely and simply. So, also, it is with the work of Madame Curé, who first discovered Radium and while Marconi has the credit for building the wireless telegraph, he merely put together a number of discoveries made previously by men who were studying pure science.

H. E. Goldberg, M. W. S. E.: It is over 20 years since I studied Chemistry. I remember that alum is to be found compounded with Aluminum phosphate and potassium sulphate. Now this Alunite, I am told, is a compound of potassium sulphate and aluminum sulphate, and that it is insoluble. I would like to know what makes it insoluble, and also is it roasted to make it into alumina, or is there some other reason?

Another thing is, how is the aluminum made? The only process that I know of is by a solution of carbon dioxide in Criolite, and I want to how how this particular aluminum is made.

Talking about the fixation of Nitrogen, in the *Scientific American,* I find that they describe the fixation by mixing ordinary soda ash and powdered iron ore with coke, heating it and passing ordinary air over it they get Sodium Cyanide, leaving the iron just as good as it was before. They claim that it does not require very much heat and that it is very commercial; the iron, of course, acting as a sort of catalytic agent, but what that is—we don't know. (Laughter.)

It seems that then Doctor Bucher went a little bit furher and he simply passed the carbon dioxide into a solution of sodium cyanide and he immediately got urea. Of course this was very expensive but is very rich, and under their process he used the urea as a fertilizer and even further than that they go on and take sodium cyanide and electrolize it and get metallic sodium and cyanogen and then they pass that into the hydrochloric acid and get oxamide. And this is insoluble and when applied to the farm it will be a practically insoluble substance, which will slowly decompose and give nitrogen to the soil and will not be washed away by the rain and would make a good fertilizer.

Now, I have been very fortunate in having read that article only a few days ago, and that is why I remememher it. Now, I would like to know something about it, if you can tell me.

Mr. MacDowell: I pass the buck. I will try and explain why it is soluble, whereas Potassium Alumina is insoluble. Just why it is insoluble as an ore, I cannot explain.

Now as to making the alumina, you take the oxide and dissolve it in caustic soda, and then you get a practically pure alumina, and then it is put into a bath of cryolite, which is melted in a carbon bath, with carbon electrodes, and the resistance melts this cryolite, and then the oxygen and alumina passing through leaves the aluminum, allowing the metal and gas to pass through the carbon and destroy a certain amount of the carbon.

Now, this material is an alumina after the potash has been taken out. You get the impurities out in this way and you get identically the same thing. You get alumina and this alumina was made in the regular cell, precisely the same as aluminum is made, from Bauxite.

Now, in regard to the nitrogen fixation, that has been running in the issues of the *Scientific American* for some time. At the time this was discussed they anticipated that one man would talk about an hour and a half, which he did, but there was no report made of the talk and he finally wrote a report, which was published in one of the journals, and it has since found its way into the *Scientific American* and a number of other discussions. As a matter of research, the laboratories have been unable to get the full fixation, but there may be a way, and it looks as if there was a process which might work out. The iron was supposed to work out and you get your cyanides in that way and you get some of your other products from it. The description is easy to read. We tried some of the processes but we have not been able to get all of the results he got, but we did get some results and it looks as if there was something fairly promising there. He takes it at a low temperature,—at about 1,000 deg. C., and he has a very narrow range of temperatures.

M. D. Kolyn, ASSOC. W. S. E.: Is any attempt being made to use the pure or free alkali we have out over the western plains?

Mr. MacDowell: At Searles Lake, 180 miles from Los An-

geles, there is an immense deposit of soda, and in that there is a lot of Borax; which contains also considerable potassium chloride. There are several large plants now starting operation, and the output of some of those plans will be sulphate of soda and products of that kind.

There are a number of other deposits in the west. One or two of them they have attempted to exploit, but they have been too far away, and have not been successful. There will undoubtedly be a certain amount of soda products made at Searles Lake, a considerable amount of Borax and, we hope, a considerable amount of potash. It is one of the most promising sources of potash in the country, because there are several million tons in that deposit, according to the analysis made of those places.

Dr. Nichols: At one time it became rather important for me to find out the exact percentage of magnesia in the shells of certain and various marine animals. About the only work done at that time had been done by a Dane, some time about 1840. It did not check up with some work that I had been doing, and when I looked at their reference, they referred back and they all showed the same thing. Finally, I found that the University of Chicago happened to have that old Danish publication, and although I could not read it, chemical analyses are made so they can be read in all languages. The chemical analyses were all different from the English, French, and American references. There had been a great many of them,—quite decidedly different and I presume, being in Danish, nobody referred back and read it.

Mr. Levy: The various findings in scientific research have often no application immediately, but sometimes in the next generation. We can hardly say that there is anything that is pure science. It seems to be a waste of time to us Americans to think that highly trained and skilled men in the Universities are putting in years, trying to find an atomic weight of Ittrium. It may be that those following us will be able to make strides and leaps and bounds as a result of this and they may work very rapidly with this very information.

Mr. MacDowell: I merely emphasize chemistry, because it seemed to me that in America we are not as far advanced in our chemical research as we are in mechanical research, or electrical research. I think that the American mind is much given to mechanical research. Chemical research is our latest and slowest research, I think. But the war has forced home to us many necessities, and forced us to a development which we had not been strong in, because our European people had been supplying us with these things so easily that we all thought we had only to buy them and not make them.

J. N. Hatch, M. W. S. E.: Rather early in this paper, our attention was called to the great necessity that has come upon us of feeding our people, and to meet this is a very alarming and perhaps, sad condition. We know, if we need more steel, how to

go about it to get it. We know, if we need more railroads, or more rifles or more ammunition, there is no question of just exactly what to do and where to put the men to work and just exactly what they are to do. Now we are up against a problem of knowing where to get more food, and nobody seems to have any idea what to do, nobody seems to have any concerted notion of what thing we ought to do. That, to me, is an alarming condition, and a condition that has come upon us without any preparation.

For a great many years the problem of getting food was the problem of each man going out and raising what he and his family needed. Now there are probably more people living in the cities who are not in any way food producers. Present conditions have brought to us now, in an alarming way, that there has to be some way of methodically providing food for this great non-producing body of people. There must be some better way than depending upon the isolated farmer raising what he needs and selling for whatever he can get for it. If conditions are not favorable he probably does not sell at all. While in the next year or so, we are really going to need this so badly, it is likely that we can do but very little. The time is now ripe when we ought to begin some concerted way of bringing all of the resources of the country to a place where there will be food producers.

It seems obvious that if the same energy of organization and capitalization were put into developing a great deal larger tracts of barren land in western states, that is now put into the cement industry, the iron industry, etc., where a large amount of capital is used to bring a comparatively small return, that we could then have a regular way of producing the food for this country, and a way that would produce it so as to be a safety valve and balance on production.

It is a known fact that the farmer, in usual times does not get enough for his products to pay him, often, to even gather them, while the city people, most of them, cannot afford to have them at all, because they are so high priced. This is mainly because there is no concerted action to produce the food in a scientific and in a large co-operative way.

It is known that the fixation of the Nitrogen of the air will produce a fertilizer that is very valuable, and very much needed, but right now, I cannot get any of that fertilizer. We know that there are thousands and thousands of acres of land to use, if we could get the fertilizer on it. We could raise from two to five times as much as before, but it is impossible to get the fertilizer, and I would like to ask what is hopeful in the way of making and distributing a fertilizer that will make the country more productive.

In the west there is unlimited water running to waste, and in a very near territory there is any amount of soil, wild land, that is not productive. At the present time the value of fertilizer is so low that it cannot be shipped any distance, and it must be used very

close to where it is produced. It must be produced in enormous quantities, and with water power at very low cost. It is practically out of the question almost everywhere, unless you can produce a fertilizer as a by-product, to make any sort of a business out of fertilizer.

Has the speaker any vision of what this fertilizer business and development of the western lands and the great problem of feeding the nation—what the development of the next ten or twenty years—will be.

Mr. MacDowell: I happen to be in the fertilizer business and I have given it a great deal of thought. Within the last six months we have organized an agricultural research department. The director of the Georgia Agricultural Association, one of the leaders in the south, has done much to increase the agricultural prosperity of that section. The question of growing food more cheaply is one of intensification, rather than of increased cultivation of land, in my judgment. There are three necessary ingredients in making the commercial fertilizer—the manufactured fertilizer today. One is the Nitrogen, which gives growth and size, and makes things green. It doesn't grow any crops, though. It is the support of the crop when growing.

The second is the Phosphoric acid, which causes the plants to mature.

The third is the Potash, which has to do with the development, and with the stiffness of the stock, so it won't go down, and with the size of the cereals, the fruits, and the various crops.

The European people, owing to the necessity and to a desire to keep as much money at home and their own growth as self supporting as possible, have gone in on a very intensive plan of cultivation. Belgium leads the world and shows an average from 37½ to 39 bushels of wheat to the acre, while the average in the United States is about 14 bushels per acre. The Belgian, French and English experimental stations in response to letters written to them, asking how they explain the practical doubling of the crop in the last forty years, replied that although giving to tillage a certain proportion and to better seed selection a certain proportion fifty to seventy-five per cent of the increase was due to intensified use of productive fertilizer. Belgium used on an average about 260 pounds of fertilizer on every tillable acre, including pasture lands, and the result was thirty-seven and one-half to thirty-nine bushels of wheat to the acre. They have grown as high as 115 bushels on one acre, by carrying it to an extreme. That is not profitable, except to see what could be done.

In Indiana, last year, an account was taken of the cost of growing grain on some 400 acres. The yield was from thirty-nine to ninety bushels to the acre. The average cost to grow corn, as I recall it, was about $14 an acre. On farms which grew 30 bushels to the acre the cost was about 36 cents a bushel. The cost on the 90 bushels to the acre farm was about 16 cents per

bushel. The 90 bushel crop was grown at this cost, figuring the seed, plowing and fertilizer, and so forth. Figuring the fertilizer at cost, charging the manure and fertilizer to the corn crop, and figuring that the wheat crop would get its benefits as well, it cost about $2.50 an acre more to reduce the cost from 36 cents a bushel to 16 cents a bushel. It does not take any more seed, and it does not take any more plowing, and it does not take any better weather conditions to grow the 90 bushels than the 30 bushels, but it takes courage and a little more money to start with.

With that example before the Indiana people there has been no great rush to buy fertilizer, and there has been nobody killed trying to buy fertilizer.

In Belgium, Doctor De Loasch tells me he has an old United States bulletin, published a number of years ago, giving in detail the experiences of Belgium's Government in trying to get the Belgian farmer to use fertilizer. They brought every excuse that the Indiana farmer brought and that the Illinois farmer and the Missouri farmer will bring to bear as a reason why they should not use the fertilizer, but they were told that the country needed it, and that they had to do it, and they were made to do it, and the result was that Belgium has fixed the average for the world.

The way I look at it, we do not want to take a lot more horses and mules and men and try to cultivate a greatly increased area, but we do want to get down to the big labor-saving method of a more intelligent cultivation of the ground in the territories near the cities, where the people want the crop, and I think that is the solution of it.

Unfortunately there are different lines of thought in agricultural lines as well as other lines. Doctors disagree, and Illinois has the idea that you can take the phosphorus, grind it up and put it there, and some time you will have a permanent agriculture.

They are absolutely opposed to the experience of Europe. They are absolutely opposed to the experimentation of Europe, because they say they have tried all these things. They don't appreciate the exhaustion of the Tennessee fields, or the Florida fields, or the South Carolina fields, in a very short time, because they are inclined to think that there are not tons enough of this to cover a big acreage, but if you take this sulphuric acid and dissolve it, it will result immediately.

What we want to do in this country is to make, as in Belgium, our farmers do what our agricultural experts say they should do. And when I say the agricultural experts, I mean the bulk of the experts in the United States.

You cannot use fertilizer and sit on the fence. You will have to work, but you will decrease your cost to the acre, and it is a fact that they will not do it until they have to, and I can tell you gentlemen that this war—this very experience we have now, is going to do more for the people in the United States in forcing them to progress in agriculture, etc., than anything that has ever happened in this country.

The trouble is we have not the sulphuric acid. We have depended on Spain for it. The bulk of our acid is made from copper refining, and from the sulphur deposits of Louisiana and Texas. Now, we cannot get them to bring the material from Spain. We cannot get them to bring the pyrites. Our consul is taking that up now. A survey is being made of the pyrites deposits in the United States and investigation is being made to see if we cannot make more of it and if we cannot overcome this very dangerous condition that we see today, and that is the need of sulphuric acid. There is nothing in everyday life as important as sulphuric acid. The consumption of sulphuric acid is the gauge of civilization in any country.

If we should take our boats from the Atlantic trade and put them into the Naval service, the situation might be very serious. Mr. Wilson has said that the government would see to it that fertilizer and agricultural implements would have the preference over all other things and what agricultural implements can be shipped will be received by the farmer in time to make use of them for this planting time to come. It is an extremely important situation and I tell you we are very much worried about it and about the pyrites situation. We hope that we can open up some deposits and we are hopeful that things can be done in the way of increasing the output of sulphuric acid.

The corn belt of Illinois is not nearly as big as it used to be, and it not maturing today because the black soil is deficient in sulphuric acid.

In South Carolina one boy grew 227 bushels of corn on one acre, and in Georgia one grew 214 on one acre, and it cost 16 cents a bushel to grow it . We have not the labor and we haven't the horses, and we haven't the time to plow up this big lot of partly developed land and land of questionable fertility, but what we want to do is to get bigger crops on the acres we plant, and reduce the price of the crops and increase our production in that way. (Applause.)

Mr. Van Pelt: I understand that there were some seven million acres in the east abandoned, even after the use of fertilizer, and the reason was that, as I understood it, the amount of fertilizer was not sufficient for a normal crop or to equal the amount which is taken out of the ground in the crop.

Doctor Hopkins, of Illinois University, had a system whereby you could get a permanent fertilizer. In other words, by adding one-half a ton of phosphate per acre a year, he keeps adding to it, so that instead of exceeding the supply, he keeps increasing it year after year.

I became interested in that matter several years ago, and have been following Doctor Hopkins' methods and have found that in the course of that time the average yield has increased from about 20 to 35 bushels, and that has been done in a neighborhood where there has been some commercial fertilizer worked.

There has been a great deal where there has been no fertilizer work, and the result is that there has been from five to fifteen bushels, on the farms I am thinking of, better than the farms around, for five or six years.

The system of getting nitrogen into the ground is through the method of putting June crops on the ground. That is, hay, alfalfa, etc., and they have the faculty of absorbing from the air and putting it into the roots. A great many of the soils in this part of the country are sour soils, and they are so acid that the June crops won't grow. They have to first fill them with limestone, and that will sweeten the soil so that these nitrogen-bearing crops will grow.

I found Doctor Hopkins' statement and system a very acceptable one, but the point that I have always understood was that enough material was not supplied to meet the needs of the normal crop. In other words, if kept up for a series of years, you would have, at the end of those years, exhausted more of these chemical phosphates and potassiums and you would have extracted more from the ground than you had to start with, and at a faster rate, because your crops would be larger, and therefore you would have a poorer soil than at the start. Whereas, with Doctor Hopkins, it would be better than at the start.

Mr. MacDowell: That is a question that has been asked for the past forty-five or fifty years, I guess, since this fertilization industry was started. But fertilizer will not give results unless there is organic matter there.

Take certain sections in the south and you will get about 14 bushels to the acre, and then put in the fertilizer and you will get about 35 bushels to an acre, because it is deficient in lime, etc. But, if you then add, say 500 pounds of lime to this soil, you will bring in a crop of 80 bushels of corn to the acre. If you use the fertilizer alone, you will bring it up to about thirty-five, but the application of the two together will bring your crop up to about 80 bushels.

There is an old theory that the bacteria in the soil have the power of making valuable the mineral constituents absorbed by the soil. That is true, if it is only there. As far as the application of the treated fertilizer is concerned, the fault with most people is that they don't apply a sufficient amount to get the best results, but the question of this large application of rock does not answer that question. We are not putting in the available phosphoric acid, except about one-half of one per cent. You cannot ship your stuff off your ground and still have it; there is no question about that, but to get results from your fertilizer, you must have humus and you must have a sweet soil.

As to the question as to how much nitrogen a leguminous crop must have—if there is a deficiency of nitrogen you will not have it. The use of those crops sours the ground. One of the causes of the Illinois sourness is the constant use of clover. But

to say that the application of nitrogen exhausts the soil is not true. In Europe where they have used it for a number of years, they are increasing the fertility. These lands have been farmed for thousands of years.

It is a mistake that the farmers make. They don't use enough fertilizer. They use 100 pounds to the acre when they should use 400 to get the best results. You have to put the phosphorus in there, and if it is in there and your bacteriological conditions are right, and if the lime is there, and there is no sourness, you will get a soil which will maintain a very much larger bacterial life than if it is not present, and that has a good deal to do with the fertility in that soil, whether you put in any fertilizer or not.

They found in Europe that under ordinary conditions they could get about 20 bushels under ordinary conditions. Now, in Germany and other places, with the application of Nitrate of Soda on wheat, and which is a proper application for them to make—they use nitrogenous matter to the fullest extent.

We believe with Doctor Hopkins in many of his recommendations and think they are all right. He is a very brilliant man, but we do think on the average soil that he is not right in his recommendations for these large applications of this rock. We would not think of growing a crop on a sour land if we knew it. We do think, and the German experimental stations think, that the best way is to take available phosphoric acid, where the plant can use it immediately, where the effect of a quick start and early maturity can be secured, but Doctor Hopkins has been blind in not trying out the other methods parallel to his methods. Everybody wants the land drained and wants it such as to support bacteria, and wants to reduce the percentage of clay because clay delays maturity materially. That is one of the reasons why, in England and other places, they put a lot of cinders and torpedo sand in their gardens. They want to reduce the proportion of clay there and want to get the aeration so that the soil will maintain bacteria.

Manures are very valuable and help give the best and most profitable results in the world. It all goes with good farming and gives better results, but they do believe that quickly available fertilizers are the most profitable and give the best results.

Mr. Van Pelt: Doctor Hopkins advises for the first year, or when you make the first application, to add some of the soluble phosphate to help along the first crop, but after that time the rock phosphate begins to become soluble. I think that he has made some experiments to test out these suggestions, by taking first a soil which is supposed to be sterile, and then experimenting with clover and so forth, and has shown that it was possible to make soluble some of the supposed insoluble compounds in the soil in question.

The point, as I understand it is this: To make it commercially profitable for the farmer to use the commercial fertilizer

at the present time, he can only put such a small amount on that it acts simply as a sort of a stimulant. In other words, if he takes a normal crop off and if he has 70 bushels to the acre, of corn, or 30 of wheat, he takes out by that crop more than is added in the material put in.

I do not know why you cannot reduce the cost to these people by making that stuff up and leaving the carrier out, and instead of having a material on which you have to pay a big lot of money for freight, if you could get 250 pounds of stuff in there, and where there was not about 1,750 pounds of a carrier and of no commercial value—why cannot some means be discovered and used whereby you could ship the 250 pounds of material to the farmer and let him mix it, and save that expense?

It seems to me that that would be a big commercial advantage, and help the farmer so that he could add sufficient quantities to the land, and in that way get a permanent system, while at the present time, with the high cost of materials, he would not add enough of the chemicals to the ground to get a permanent stimulant. He will have to put fertilizer in the ground in addition to what he has exhausted from the supply already in the ground.

Mr. MacDowell: That is a question which comes up very often. A piece of bone, for instance, contains about 22 per cent of phosphoric acid, and the balance is lime and magnesia, etc. You might concentrate that, but it is not commercial.

Now, we had a meeting here not long since, where we were talking about making a product running about 75 per cent ammonia. There is a whole lot of cheap material that only runs three and one-half and four per cent, and all that material has to be used. You cannot get the farmer to buy concentrated products today. He buys fertilizer just about as he buys coal, at so much a ton.

You cannot ship it in the way you suggest; it is a question of distributing it in some uniformity. The concentrated materials are used, and we sell hundreds of thousands of tons of the concentrated material. We have a very large business for such in the truck garden sections. A farmer can use very much more than he does; he can use up to a certain point, but there is always a point at which you cannot go out and make a profit, but the farmer makes a mistake in not using anywhere near enough. If he wants concentrated fertilizer, the manufacturer would prefer to ship it to the farmer, but the farmer, as a rule, wants to get the cheapest thing per ton he can get, and you can talk to him until he is black in the face and he won't buy twenty-five dollar fertilizer, when he can get something for eighteen or twenty dollars a ton, and yet, he will really be paying twice as much for it.

Mr. Van Pelt: Well, the point I wanted to bring out was this: That if you take this concentrated fertilizer and then, when it gets to the farmer, tell him to mix it with so many pounds of soil.

Mr. MacDowell: Very little of the fertilizer shipped out, and only a very small percentage, has any carrier excepting the natural ingredients. Some have to have a little something to break them up and to get them so that they will drill, as they must be in that condition so it can be fed all over the acre ,and not all in one place.

Everything carrying nitrogen is used, that can be shipped, and a very large tonnage, perhaps 30,000 tons of garbage tankage in Chicago, is used for that purpose. It should be used and that should be saved whether there is a profit in it or not. It came from the farm, and it ought to go back there. All those things ought to be used and we have to take these low grade materials as well as the others, in order to manufacture it as it is needed. There are seven and one-half million tons of it manufactured a year, and we have to use it.

ECONOMIC INDUSTRIAL APPLICATIONS OF ELECTRICITY

By Norman T. Wilcox*

Presented April 23, 1917.

ECONOMIC USES OF ELECTRIC SERVICE

As my experience in recent years has been largely commercial as well as engineering there are some things that particularly appeal to me. I have been particularly impressed by the development of higher efficiencies of production and consequent lowering of ultimate costs resulting from the application of electricity to manufacturing operations; also by the great opportunities offered by the application of electricity in reducing human labor, both in the home and elsewhere, with its consequent improvement in human efficiency.

The suggestions I have to offer here tonight are not intended to be needlessly technical, but are made with the intention of pointing out some real practical applications which are already being used to a considerable extent and which, if properly appreciated, will materially aid in the attainment of great economy.

In the coming years of sharp world wide competition, the aggregate of such efficient application will mean much in affording all of our communities the advantage so necessary and so much desired for the coming years. This being the case, it is important that each and every citizen should appreciate his personal responsibility and do his individual part in attaining higher efficiencies in all lines of endeavor. .

Electricity is one of the greatest agencies in attaining this result. It is much easier to sell power to mill people and others today than was the case even a few years ago.

INDUSTRIAL AND DOMESTIC SERVICE

The application of industrial and domestic devices for using electricity is proving advantageous, as is evidenced by the enormous sale of domestic devices. The saving of labor to lighten the duties of the housewife, the general improvement of home service, and the comfort which results from the attaining of greater efficiency in the home, results from the use of electric energy. The electric "Mary Ann" does not strike for higher wages, stays in afternoons and evenings and sticks to the job day and night, 365 days in the year, thus saving much nervous energy.

The increases in production due to the more regular speed where electric drive is used, materially increases quality as well as quantity of production. In textile mills this increase has been found to be from 3 to 20 per cent, the latter, of course, being an exception. In addition to the absolute increase in production is

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the fact that there are materially less rejects due to faulty work, so that the addition to net profits resulting from the use of electric power is a very material one. That this advantage is a very real one, and now appreciated by manufacturers, is typically demonstrated by the experience of textile manufacturers in the city of Lowell, Massachusetts. Some 14 years ago the Merrimac Mill at Lowell had a water wheel driven, 300 kw. alternating current generator driving four or five motors which operated looms and similar textile machinery. This was the only alternating current motor drive in the city which was using approximately 100,000 h. p. for manufacturing purposes.

Today 80 per cent of the power driving the textile machinery in Lowell is alternating current derived either from central station or from very large plants at the mills. If the central station plant had been equipped with turbine generators of the sizes and efficiencies now obtainable, it is quite likely the major portion of this drive would now be supplied by the central station. This in spite of the fact that considerable steam is required for auxiliary operations.

Only those of you who have had occasion to check such matters carefully can realize how variable are the costs in the ordinary plant that is depending upon men who have not had the experience or means to enable them to properly check up operating expenses.

I personally know of one case of a large steam electric generating plant which had been carefully systematized and operated for a long period under this method. The plant made a careful check in boiler and engine rooms every 6 hours and 12 hours and, of course, took the total for the 24 hours. The labor employed was exceptionally high class, both in the boiler room and elsewhere, and yet, if the check system was given up for ten days, there was just about 10 per cent loss in the fuel economy. Of course, this proportion would not be obtained progressively for a longer period. However, this result simply shows the importance of careful and continuous attention to detail and of having a high class, high salaried force to insure economical results.

It is obvious that isolated plants, especially the average one, cannot operate so as to conserve fuel and other resources as can the central station. We all appreciate that gasoline is getting scarce and the truck of today is using a relatively large amount of this form of energy for the work done. There seems to be much doubt as to where the supply of fuel is coming from in the future when existing supplies are exhausted. The new plan that has recently been discussed of offering service to electric trucks in the city, which will include the garage, ordinary service and renewals of batteries, making the charge for energy and the total service on a flat rate basis, should be the means of enormously increasing the use of electric energy, and incidentally the means of saving much of the natural oil product which is being used in a grossly waste-

ful manner in the generation of power and to drive these machines.

Here in Chicago there is an immense number of electric trucks which should use electric drive that would result in a tremendous saving of natural supplies of all fuel.

ECONOMY OF ISOLATED PLANTS

The advent of great central station generating plants has brought about the development of organizations employing the most competent and highest priced technical talent, both for the designing and the operation of these plants.

Compare, if you will, the coal consumption of the ordinary small plant with its comparatively inefficient and very poorly paid operating force, and with a coal consumption of anywhere from 4 to 12 or 15 pounds, or more, per kilowatt hour of equivalent output, with the economies attainable from a large unit steam turbine plant, some of the large units showing an economy of as low as one pound of coal per kilowatt hour.

As a result of these developments, the central station electric supply plants and similar utilities which have been dedicated to public service, have been able to progressively reduce the cost of both energy and light to the ordinary citizen for use in his home. This in spite of the constantly rising cost of almost all other commodities. Further broadened use and development of public service agencies will result in continued advantages to the public.

Although big investments for expensive and large distributing systems are necessary to get this energy to the customer, is it not the part of patriotism to encourage these developments and to make possible these great economies in the saving of fuel which can be attained only in this manner?

It would seem that true conservation calls for hearty cooperation on the part of every engineer in order that we may conserve for future generations, the priceless supplies of coal and oil fuel which nature has bestowed upon us and which in the not distant future must come to an end. Should not every conscientious engineer labor to bring about a result so advantageous to the country as a whole?

THE ELECTRIC VEHICLE

Electric vehicles, especially in large and comparatively level cities, have a wonderful possibility of conserving much natural energy now wastefully used in the form of gasoline.

The development of the electric truck and of methods of use allowing of a definite charge per month for the use of batteries, electric energy, etc., is a forward step in the direction of greater efficiency and true conservation.

The Bush Terminal in New York uses 12,000,000 kilowatt hours per annum for charging of electric trucks alone. This is some indication of the possibilities of this large and practical field for the use of electric energy.

REFRIGERATION

At first thought the average person would not realize that electric power as applied to refrigeration is a development in the line of greater efficiency. Yet we must recognize that artificial refrigeration results in the conservation of much perishable food and allows of a more even distribution of these products over the whole year.

The application of electric energy for this purpose results in a great saving of fuel which, in future generations, will be almost priceless. The improvement in the quality of ice distributed for domestic use results in a conservation of health and increase of comfort, which is also in the line of true efficiency.

In Chicago alone, twenty-six plants indicate that the public understands and appreciates the advantages of this application.

ELECTRO-CHEMICAL APPLICATIONS

The use of electric power for electro-chemical work, which is a comparatively new field and doing much at present, affords even greater promise for the future.

The formation of the recent joint committee of the American Electro-Chemical Society and the Electro-Chemical Division of the Power Sales Bureau of the N. E. L. A. will doubtless be an effective means for increasing the efficient results of this development.

ELECTRIC STEEL FURNACES

Outside of the steel trade few people appreciate the rapid growth in the use of electric furnaces for the production of the highest grades of steel and steel castings.

This growth has resulted from the efficiency of electric power and has for the most part occurred within the last five years, the greater portion of the increase occurring in the last year or two.

Up to March 1, 1917, at least 158 steel making electric furnaces had been contracted for or were at that time in actual commercial service in the United States. These furnaces if operated twenty-four hours a day, six days in a week, would have a total capacity of 1,000,000 tons of steel per annum.

Ten years ago, or less, there were but a few tons of electric steel produced in this country. The production of a million tons of steel made from cold scrap would represent at least 600,000,000 kilowatt hours per annum. A large portion of this energy should be supplied from public utilities, and should contribute its part in widening the use of public service investments, with consequent benefits to the communities served.

Because of its uniformity, greater freedom from segregation and its greater homogeneity, *electric* steel is somewhat higher in tensile strength and elastic limit than steel made by other processes. Owing to its greater density the electric steel shows a marked resistance to fatigue.

No doubt the discovery that the best crucible quality steel can be made in the electric furnace, and the further fact that crucibles have become almost prohibitive in price, has contributed greatly to a rapid realization of the great practical value of the electric furnace.

BASIC OR ACID PROCESS

In the open-hearth furnace the melting is accomplished by a flame, which, under the best conditions, is oxidizing in its nature.

In the basic open-hearth process, carbon, phosphorus, silicon, manganese and some sulphur are removed from the bath. In the acid open-hearth process only carbon, silicon and manganese are removed.

Where the heat is produced by an electric arc, it is possible to melt and refine a charge of metal in a neutral and reducing atmosphere free from the foreign materials incident to the use of an air blast.

In an electric furnace the refining may be commercially carried out to a much higher degree of perfection than is possible with other methods. All methods of steel making, except the electric furnace, have quite definite and limited fields of use. On the other hand, the electric furnace can be used to produce steels equivalent to any of those obtained through other processes.

Looking at the situation broadly it may be stated that where the electric furnace is used for melting and refining, and in cases where superiority and uniformity of product is essential, the electric furnace competes successfully with the open-hearth furnace. This is because the increased cost due to the use of electric power for melting is offset by the advantages of refining which are peculiar to the electric furnace.

A crucible furnace does not make any better steel than can be made commercially by the use of a properly designed electric furnace and is handicapped by the necessity of carefully selected material for use. The use of the electric furnace makes the manufacturer, to a great extent, independent of the high labor costs and high cost of the extra selected materials necessary for the production of the best quality crucible steel.

It may be of interest to note that for average conditions, good raw material and 24 hour operation, 600 kilowatt hours per ton of melted metal should be sufficient for the manufacture of ordinary high grade steel. Carbon steel may require some less and some alloy steels may use quite a bit more. Less than 24 hour operation will somewhat increase the kilowatt hours required per ton of metal.

If the melted metal is not poured quite close to the furnace but is carried some distance before it reaches the mold, extra energy will be required to offset the heat losses during the period that elapses before the metal is poured. The kilowatt hours may also be increased as a result of poor organization of foundry force or as the result of lack of skillful and well-directed operation.

In some cases the same furnace may be used in the production of high grade cast or malleable iron. Owing to the low melting point, less energy is required for cast iron than is necessary in the production of steel.

Small furnaces have been developed even in the multi-phase type down to capacities as low as one-half ton of metal per heat. A furnace of this size will require from 100 to 125 kilowatts of capacity and when operated multi-phase will run on a power factor of approximately 90 per cent. The larger furnaces as now installed, for most efficient operation require approximately 250 kilowatts of capacity per ton of metal per heat.

In order to obtain the desirable rapid melting down, the transformer connections are now arranged for more than one voltage and furnaces so arranged that after extra heat is absorbed by the cold metal the voltage may be reduced and the furnace refractories saved from undue wear. This is important.

As many, if not most, of the small steel furnaces, as well as some of the larger ones, can be so operated as to keep off the peak, the furnace load is an attractive one.

Smaller furnaces will, no doubt, be eventually used in many small factory foundries. Small or irregularly operated furnaces will, of course, require more energy owing to the losses due to radiation, heating up the furnaces, etc., but on the whole it may be said that the electric furnace is another one of the modern instruments which are broadening the use of electric energy and contributing their share to the ultimate efficiencies.

Load factors claimed have no doubt been higher than attained in actual operation. With a 30-minute demand and a single unit plant a 45 per cent load factor, even when the furnace is operating 24 hours a day, is the exception—not the rule. Where a greater number of units are used the diversity effect may result in a better load factor.

Power factors and energy for a furnace load should always be rated and measured on the primary side of the supplying transformer, and operating data should be based upon this condition—not on data obtained from the secondary side of the transformer. This procedure is necessary in order to avoid troubles incident to the use of instruments placed in the arc circuit.

The quality and kind of scrap material used will have a marked effect on the kilowatt hour consumption per ton of product. Selected material will afford selected results. If high grade, low phosphorus, low sulphur scrap is used, less energy will be required and the fixed charges, as well as other charges such as labor, will be materially less than if inferior materials are used.

Owing to the superiority of the arc furnace over the crucible method of producing high grade steel, and owing to the further fact that the arc furnace does not necessarily require the highest grade of raw material, as does the crucible method, we may confidentially except the crucible method, generally speaking, to become a thing of the past because it is becoming an economic impossibility.

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As electric furnace practice is better understood and costs of furnaces become lower in price, we may expect a more general and extensive adoption of the small sized furnaces in many manufacturing plants that have not as yet seriously considered this plan of operation as a practical possibility.

The operation of the electric furnace, especially where selected material is used is ideally simple and satisfactory and should result in increased efficiencies.

Electric furnaces cannot be expected to take the place of the ordinary cupola, such as is used for the making of common grades of cast iron. However, we should not lose sight of the fact that the electric furnace is the only apparatus which will successfully produce all grades of material from and in the same furnace. These products range from superior quality cast and malleable iron, up through the list of various grades of steel, including the finest grades of crucible and tool steels.

FURNACES FOR NON-FERROUS METALS

The electric furnace will also be used extensively in the melting and treatment of other metals, such as red brass and some alloys.

There are several of this type of furnace now in operation in this city. It will be noted that all of these operations are comparatively recent developments, which accounts for the fact that this type of apparatus is not more generally used.

There are so many possibilities in the increased and broadened use of electric energy that it is not worth while to further enumerate these applications at this time. Broadly speaking, the greatest efficiencies in the conservation of coal, human energy and human comfort are to be obtained by the broadest possible use of electric energy and service such as is now possible. I am, therefore, recommending the possibilities of these applications and their resulting economies for your consideration during the coming years, and I believe that a careful consideration of the possibilities of the wide and economic application of electric energy will result in further interest on the part of all who are anxious to make our cities and the country at large still more satisfactory as a place of residence for the average human being.

DISCUSSION

The Chairman, Mr. A. L. Perry: I will ask Mr. George H. Jones of the Commonwealth Edison Company to take up the discussion.

Mr. Jones: Mr. Wilcox has covered the matter very fully and emphasized the great developments which have been made by the use of electricity during the last few years. In order to partly realize how great this development has been, it is only necessary to look back a very few years to the time when even the electric

flatiron was considered an experiment and its reliability undemonstrated. It is apparent that the sale of electricity has become so general that its use one way or another has extended to practically every line of industry. Its use is bound to extend very greatly from year to year as the many labor saving devices which it makes possible become increasingly valuable as labor becomes more and more scarce.

One point I wish to emphasize is the important function central stations are performing in providing an ample and flexible source of supply to meet these growing demands for electrical service. The factory manager need no longer worry about the necessity of increasing his power plant as his business expands. The central station takes care of this problem for him and leaves his mind free to develop his own business.

One of the subjects treated by Mr. Wilcox was the use of electric power in the manufacture of steel. Great progress is being made in this line, and a business is being built up which promises to be increasingly profitable, both to the steel manufacturers and to the power companies furnishing energy. We have with us tonight Mr. J. M. Olmstead, Vice-President of the Electric Steel Co., who has been giving this matter a great deal of attention during the last few months. Mr. Olmstead is engaged in the manufacture of a high grade of electric tool steel and I should like to have him tell us something of his experience.

Mr. Olmstead: For fifteen years I have been on the other end, where I have been using steel castings, and higher grade steels, but we started out with an electric furnace to determine whether or not it was possible to make steel castings that were more useful. That is to say, to overcome the greatest difficulty that the user of machinery and steel castings comes in contact with, the losses after he has put his material and labor into the steel castings. Our average percentage of rejects is illustrated by a specific job in an eastern plant where I have been for the last fifteen years. A gear blank showed from 27 to 32 per cent rejects after they had either been entirely cut or partially cut. That meant that our cost on these gears was raised anywhere from two to eight cents a pound over and above the cost of the casting, as it was bought.

Besides slowing up our production, those losses were made in cutting. Therefore, in starting this plant in Chicago, we were particularly keen to learn whether or not we could get away from those losses and reclaim the steel casting business. A certain part of the business which had previously been steel castings had gone to forgings because of the lack of uniformity, blow-holes, shrinks, etc.

Perhaps the best way to put it before you is to give the specific results: We are now just completing a run of some 12,000 gear blanks, which will weigh approximately eighty pounds apiece, and our percentage of rejects, on something like near 10,000, is less than one-tenth of one per cent.

Those blanks are as uniform as any forgings I have ever seen.

They make a much more satisfactory gear. If there are any forge gentlemen among us tonight, they may choose to contradict me, but we have the evidence. Those gears make a more satisfactory job for the user, in that we are able to run steel of from 60 to 80 per cent Manganese, with a Silicon content of approximately 35 per cent, and Phosphorus and Sulphur operating on an acid bottom of below .04 per cent.

Those gears present a better rolling surface than a forged blank from lower carbon, running about 35. We are not confronted with the necessity of heat treating those blanks at all, and the possibility of a lack of uniformity due to heat treatment, which is a great problem with most steel makers today, or the problem of fatigue, which all users have to contend with at times.

Our product is essentially steel castings. We started our plant with a single phase furnace, operating on an acid bottom. We did that because we tried to capitalize our plant, but not over-capitalize it, in an attempt to make good steel castings in a furnace in which we might also want to make high grade tool steel. We found the single phase furnace, so far as we have gone, to be very much faster than the multiple phase furnace.

Mr. Wilcox spoke of the power consumption per ton of metal melted. I do not know of the multiple phase furnace working as low as the single phase, but there may be some. Our average consumption is between 550 and 575 kw. per ton of metal melted, operating on a 24 hour basis.

The statement Mr. Wilcox made as to the advisability of 24 hour operation is, without doubt, not only the best practice, but is almost a necessity in the operation of an electric furnace. Therefore, it is a much better proposition for a central station, as it gives a fairly good load factor. Our load factor is running between 55 and 60 per cent. We could better that, and expect to better it very shortly, when we start the operation of what we choose to call our larger unit, which will have a faster method of charging. Our present furnace is only one ton capacity.

The serious situation, however, at the moment before the Chicago furnace users, is that of electrodes. There are two types of electrodes used—the amorphous carbon and graphitic. We have not used the amorphous up to the present time. There is not, at the present moment, anywhere near the capacity for making electrodes in this country necessary to take care of the furnaces in operation, and far from enough to take care of those contemplated. Therefore, it is a matter of very keen competition on the part of the electric furnace users, to get the electrodes necessary to operate.

The International-Johnson Company, at Niagara Falls, is making all the graphitic electrodes. It is necessary for them to keep men out in the steel plants all the time to see that no one gets stock ahead, and piles it up.

We have had a man at Niagara Falls for the last few weeks and have to keep him there in order to keep going. I mention this,

because, in speaking of the possible lines of endeavor in the electrical field, there is a tremendous field for the moment for the manufacture of electrodes, and particularly graphitic electrodes.

Our experience in converting the electric furnace metal into steel castings compared with converter processes has been very good. I had a discussion not very long ago with a strong converter man. I told him that I would try to refrain from discussing it too strongly from a metallurgical standpoint, but would confine myself to the fact that I had seen castings made from converters, in a good many places, but we would be willing to take our castings, or the castings from other electric furnaces when operated with reasonably good foundry practices, putting them in comparison with the product of the converter. I am willing to leave it to any fair judge as to which is the better. Furthermore, the fact is that if the converters can make a more uniform and denser casting, they do not do so. I don't know why it is, but they do not do it.

We have a converter operating in a plant here in Chicago which is not directly allied with us, but which we watch closely, and our castings are very much more uniform and they are denser. We have very much less segregation. Our chemical analysis is much more uniform and is lower in phosphorus and sulphur. Our scrap has to be carefully chosen. We get no reduction of phosphorus and sulphur and it is not our intent to get it.

The great problem with steel casting users today is not the chemical analysis. They do not care a rap about that as long as it is not too high in sulphur. What they want to get away from is the lack of uniformity and blow-holes, particularly on machine work. I think the electric furnace metal is freer from most of the oxidizing gases than the crucible metal. Mr. Merriam, General Superintendent of the Symes plant at Lockport, using the crucible process, tells me that their product is free. They believe, however, that there are certain things in connection with the heat treatment of their steel, after it has been poured into ingots, that they have not yet been able to work out with the electric method so well as with the crucible method.

In the present market our metal cost is lower, due to the fact that pig iron is running anywhere from seventy to seventy-five dollars a ton. Scrap pig iron, such as we use, is anywhere from thirty to forty dollars. The other ingredients used in the manufacture of converter metal, coke, etc., are almost on a like comparison with pig iron and it has been very hard to get any good coke.

I think that it is safe to say that the cost of electric furnace metal, per casting, is sufficiently close to converter cost on either normal or an average basis, so that there is not much to fear from the converter on that score.

The question that we are interested in, and the Power Companies are interested in, is knowledge as to whether or not it is possible to operate a single phase furnace at a power factor sufficiently high to make it a load which does not have to be penalized.

I will say, frankly, that our power factor in the small furnace has not been as high as we would have liked to use it. In our larger furnace, in a few weeks, we hope to be able to demonstrate this. The Edison Company hope, more than we do, to show a power factor sufficiently high, so that there will be no feeling on their part that a single phase furnace is a poor load.

A single phase furnace is faster for steel casting work. There is no use in the operation of a furnace for small casting work, to utilize an equipment that is over good. I think that there is as much to be said in disparaging over-capitalization as there is in under-capitalizing a manufacturing unit of that sort. We try to get it as evenly balanced as possible, the same as with any tool or equipment.

The question of heat-treatment and annealing of steel castings has been a more or less hit-and-miss proposition. We had an occasion recently to take a certain casting, which we were making, and anneal it ourselves in a fire furnace. We sent a similar casting to four other steel foundries, and asked them to anneal and return them. We examined those four, together with our own, and we found that the annealing was less than 50 per cent efficient. In other words, it was no good. An annealed casting has to be 100 per cent or it is no good. That, I think, comes about through the lack of uniformity in the control of the oil flame.

I recently examined some induction type annealing furnaces operating in the east. I believe that there is as big a call in that respect for electric energy as any I know of. The steel which I examined indicated almost 100 per cent efficient annealing over a period of some months. That is steel, coming out of the anneal once a day, and as the superintendent told me, you can tell it what to do at 3:00 o'clock in the morning and it does it, without an operator to control it. You do not need any skill of any men, and it has so little scale that you could almost claim there was no scale on it.

I might go on and tell you quite a little more of some of our experiments, but I do not think you are extremely interested in that. If there is any question anyone would like to ask me, and which is not too technical, I will be very glad to answer it.

A Member: What do you mean by operating on an acid bottom?

Mr. Olmstead: There are two methods. The basic bottom on which the steel is melted, results in a chemical action and removes the phosphorus or sulphur, or reduces it. In an acid lining we use silica, which does not reduce the phosphorus or sulphur from the scrap charged in the furnace.

J. N. Hatch, M. W. S. E.: Can hardened lead be melted over again and cast, and still keep its hardness?

Mr. Wilcox: Oh, yes. The metal is made in an alloy which has peculiar properties.

Mr. Hatch: Does its melting point remain the same?

Mr. Wilcox: That I cannot say. I can only speak of it as a general development.

The Chairman: In this economic industrial application of electricity, gentlemen, it is important to remember that electricity is nothing but a labor saver, and is the most useless thing in the world as electricity alone, but it is probably one of the best things in the world, as a labor saver.

In making up the estimates for future business, as is the practice with most of the companies, they get together once a year and attempt to predict what business they will have during the time anticipated, so that they can base their manufacturing requirements on that. One company, of which I was a member a year ago, attempted to sum up the proposition so that they would have it before them and then they would guess at the percentage. That would form the basis of their manufacturing requirements for the year.

In recent years that method has proven entirely inadequate, due to the fact that there are two fundamental changes going on in the cost of labor and material and fuel. Just for example, we will take the mining industry. The cost of coal, copper and iron has greatly increased, and an electric locomotive will replace about eight or ten mules and an equal number of men, and the only limit on this point is production facilities in the manufacturing plants. We know that in a large number of instances, a number of copper mines have been practically idle due to the fact that they cannot get the labor. In some of the mines, they had to shift the cars about by hand. They are very anxious to get locomotives.

Some months ago Mr. Lidbury told us about what electricity and electric steel, and the electric industry were doing for the automobile trade. Now, these gentlemen who spoke to us tonight, both Mr. Wilcox and Mr. Olmstead, have told us what an excellent product we could get from the steel furnace. I should like to ask the approximate cost per k.w. hour to give us the commercial product. Mr. Lidbury further remarked that evening that the present methods were so inefficient that it was not likely that it would be introduced in this country, unless in a government plant. It looks now as if the electric steel furnace is going to be one of the very best uses for electricity and some central stations are making very large additions to their plants solely for the purpose of encouraging the manufacture of electric steel.

Mr. Wilcox: I do not know that there is very much to say except in regard to the electric heat-treatment furnaces which have been referred to here, but it was my privilege, a short time ago, to go into a plant of the Otis Elevator Company, in Buffalo, where they have two double phase furnaces operating 24 hours a day. I found on one side two electric heat-treating furnaces, and I asked what they thought of them. They said that they would not be without them, and could not get along without them. And at Sharon, Pa., in making steel couplings, for freight cars, they have found that the product is much more uniform in quality than the old kind, and it is interesting in that connection to know that they not only are

using a number of electric steel furnaces for producing the metal for the casting, but after the castings are made, they are heat-treated electrically, in machines which are almost exclusively automatic in their action, even to the punching and re-heating of the material.

But there is going to be a very large field for the use of electric energy in operating heat-treating furnaces, also in japanning and such work. The freedom from the danger of an open flame, and other dangers that are incident to the use of open flame ovens, has caused the manufacturers to look about to see what they could do.

I was at my brother's factory, back in Connecticut, a short time ago, when he showed me an electric oven he had just put in. I asked him what he did that for, as I knew he was paying a pretty good price for juice, a good deal more than we pay to the Edison Company.

He said, "We get a good product and no oxidation, and no effect from the gas, and furthermore, it is cheap for us." I think they were paying something like two cents a k. w. hour.

It is hard to appreciate, unless you happen to look into these things, how many advantages there are for the further use of electric energy, and, in that use, for the greater economy of operation. You get economies in various ways. You get it from an improvement in the quality of your product, and from the greater uniformity, as well as, sometimes, from the cost alone.

The cotton mill manufacturers, and many other manufacturers, could well afford to pay even more than they do for energy for manufacturing operations, if the proposition was carefully analyzed, because of the great benefits through the use of the electric energy.

In our homes it means a great deal to the housewife, as I suggested, and I think some of you men folks do not realize just what it does mean to the women folks in the home, and it saves a whole lot one way or another.

NOTES ON ROAD BUILDING IN WASHINGTON'S TIME*

By A. N. Johnson, *M. W. S. E.***

Presented February 19, 1917.

Road building, as we know it today, did not begin in the United States until after the Revolutionary War. Prior to that time the work that had been done was chiefly in opening and marking trails, at first for pack-animals only, later widening these to accommodate wagons. In 1750 routes were authorized to be laid in central New York and Pennsylvania merely to accommodate pack-horses.

In many sections the location of the trails and the roads following them were notable in that they kept to the highlands or the ridges. When it was necessary to cross a stream the road would follow the ridge as far as possible, then make a sudden dip. As a consequence, at the stream crossings the grades were excessive, far more than the general contour of the country would demand. This feature of road location is particularly noticeable in Maryland and Virginia.

The administration of the roads in colonial times was at first in the hands of the individual settlers and later was placed under the auspices of the various towns, plantations or parishes, in general being patterned after the English system, which it might be said, in passing, was at this time about as wretched as it could well be.

The year 1775 saw the beginning of corduroy roads and it is remarked that this was a work "that was done by everybody in particular and by nobody in general." A traveler would become stuck in the mud and would build a short bit of corduroy road to help himself out, which was left there for the benefit of other travelers.

Harriet Martineau remarks that, "corduroy roads appear to have made a deep impression upon the imagination of the English, who seem to suppose that all American roads are of corduroy. I can assure you that there is a large variety of American roads . . .

"Lastly, there is the corduroy road, happily of rare occurrence, where if the driver is merciful to the passengers he drives them so as to give them the association of being on the way to a funeral. There are involuntary sobs on each jolt helping the resemblance. Or, if he be in a hurry he shakes them like pills in a box."

Until 1790 there were not to exceed 1,800 miles of post roads in the United States. It was about this period that broken stone or macadamized roads were first built. Successful roads of this construction were in use a number of years before they were introduced into England by Macadam in 1816. Macadam came to England from

*Notes for this paper were compiled from "Historic Highways of America," by A. H. Hulbert, 1902-1905, Arthur H. Clark Company, Cleveland, Ohio, Maryland Geological Survey Report for 1899, "Highway Legislation in Maryland," by St. George L. Sioussat, and "Stage Coach and Tavern Days," by Alice M. Earle, 1900, McMillan & Company, New York.

**Consulting Highway Engineer, Portland Cement Association.

America in 1783 and was no doubt acquainted with the progress made in the United States in this form of construction.

One of the earliest macadamized roads was in Pennsylvania, the Philadelphia-Lancaster turnpike, which was completed in 1794 at a cost of $465,000.

The president of this turnpike company issued in 1796 the following notice to the public: "Be it further enacted by the authority of aforesaid that no wagon or other carriage with wheels, the breadth of whose wheels shall not be four inches, shall not be driven along said road between the first day of December and the first day of May following in any year or years, with a greater weight thereon than 2½ tons."

There is a record of an earlier turnpike in Virginia built in 1785-86. This road connected Alexandria with the lower Shenandoah.*

The importance of road communication between the Ohio country and the East was early appreciated and was constantly in the mind of Washington, to whom is attributed, more than to anyone else, the attainment of the great highway across the Alleghenys. A connecting link in this route was from Fort Frederick to Fort Cumberland. Fort Frederick was erected in 1756 and the necessity for a short route from Fort Frederick to Fort Cumberland soon became apparent. After the capture of Fort Du Quesne a committee of the Maryland Assembly was ordered to make a report of the cost to connect Fort Frederick and Fort Cumberland by a wagon-road. The following extract is taken from this report:

"Your committee have made an Enquiry into the situation of the present wagon road from Fort Frederick to Fort Cumberland, and are of the opinion that the distance by that road from one fort to the other is at least eighty miles, and find that the wagons which go from one fort to the other are obliged to pass the Potomac River twice, and that for one-third of the year they cannot pass without boats to set them over the river.

"Your committee have also made an Enquiry into the condition of the Ground where a road may most conveniently be made to go altogether upon the North Side of the Potomac, which will not exceed the distance of Sixty-two miles at the expense of £250, current money, as may appear from the following estimate, viz.:

"An Estimate of the Expense of clearing road from Fort Frederick to Fort Cumberland, and the Several Different Stages:

For clearing from—	£	s.	d.
Fort Frederick to Licking Creek, 3½ miles	0	0	0
Licking Creek to Praker's Creek, 8½ miles	12	0	0
Praker's to Sideling Hill Creek, 12 miles	16	0	0
For a bridge over Sideling Hill Creek	60	0	0
Sideling Hill Creek to Fifteen Mile Creek, 4 miles	22	0	0
Fifteen Mile Creek to Town Creek, 15 miles	140	0	0
Town Creek to Col. Cresap's, a good road, 4 miles	0	0	0
Col. Cresap's to Fort Cumberland, wants clearing, 15 miles	0	0	0
	250	0	0

*"Stage Coach and Tavern Days," Earle, p. 282.

"Your committee are of the opinion that a road through Maryland will contribute much to lessen the expense of carrying provisions and warlike stores from Fort Frederick to Fort Cumberland, and will induce many people to travel and carry on a trade in and through the Province, to and from the back country."

The first road to be built across the mountains was constructed by Washington as far as the Great Meadows. Washington had been placed second in command to Colonel Fry on an expedition sent out by the Governor of Virginia, November 15, 1753, with a letter to the French Commandant of the Fort erected by the French on the Ohio river. Colonel Fry was killed by a fall from his horse, which left the full responsibility of the expedition on Washington, who was barely twenty-one years old. He proceeded to Wills Creek, Maryland, and in his journal he describes this section of the road "the worst road that was ever traveled by man or beast."

From Winchester to Wills Creek, Washington was obliged to build the roads as he went to make them passable for his horse and wagons. Beyond Wills Creek he built a road, the route for which had been worked out by Col. Cresap three years before. This section of the road was known as Braddock's Road.

The writer walked over the portion of this road over Wills Mountain during the Summer of 1899 and its course could readily be followed although much overgrown with brush and many trees of considerable size. This was the only road to the West until 1818, being in use for sixty-five years. The National Road opened in 1818 was relocated around the end of Wills Mountain, following the course of Wills Creek and eliminating entirely the steep grades of the route followed by Washington. It is probable that at that time he considered the obstacles to be met in following along the creek greater than going directly over the mountain, which route was through a saddle-back and was the most available of any direct crossing.

The following description, by a writer of the times, of the early work on the National Road begun shortly after Washington's death is of interest:

"That great contractor, Mordecai Cochran, with his immortal Irish brigade—a thousand strong, with their carts, wheelbarrows, picks, shovels and blasting tools, graded the commons and climbed the mountain side, leaving behind them a roadway good enough for an emperor." This road, called the "Chain of the Federal Union," was perhaps nearer to the heart of Washington than any other public enterprise of the time."

At the time of Washington's death the era of turnpike building was well under way, and for nearly forty years thereafter the method by which most of the important road work of the time was financed and administered was by private turnpike companies.

The amount of travel that many of the earlier roads carried was remarkable. On the Mohawk Turnpike from Albany west to

Utica, began in 1787 and finished in 1800, a steady stream of settlers flowed westward from New England. Great wagons filled the road. Within 50 miles of Albany there were 52 taverns, but these could not provide sufficient accommodations.

The construction of the great westerly route from Baltimore through Frederick, Hagerstown and thence to Cumberland, was begun in 1787 by the counties but was turned over to private control in 1804 when the road was completed at the expense of certain Maryland banks. The travel was so great that it proved to be a wonderfully profitable investment, yielding 20 per cent for several years.

After 100 years we see today another era of building long stretches of roads, but financed and administered by the states. These roads will add to and strengthen the "Chain of Federal Union" so well begun by Washington.

IN MEMORIAM

FREDERICK SEWELL BROWN

An Appreciation.

Frederick Sewall Brown, member of the Western Society of Engineers, died May 31st, 1916. This Society then lost a member who was an honor to our profession. His family and friends parted with one whom they loved for his endearing qualities and respected for his sterling worth. He was the son of Henry Sewall Brown and Hannah E. (Call) Brown, both of Bangor, Maine, born on October 18th, 1854. On February 14th, 1877, he married Miss Ella May Foster. She, two sons and three daughters survive him and he had the comfort and satisfaction of seeing his children attain man and womanhood.

He left his boyhood home in his 'teens and entered the employ of S. B. Cushing & Company, Civil Engineers of Providence, Rhode Island, and was, at a later period employed by J. Albert Nourse, C. E., of the same city. After fitting himself, by study and the practical application of what he learned to the work on which he was engaged, he entered the service of the Government at St. Paul, Minn. In 1880 he entered the engineering service of the Chicago, Milwaukee & St. Paul R. R. and became secretary to that veteran engineer, Don. J. Whittemore. He had trouble with his eyes, and, fearing that this trouble would increase until it incapacitated him for the practice of his profession, he decided to take up contracting and he purchased an interest in a stone quarry at Anamosa, Ia., associating with himself Mr. Erickson, a practical stone mason.

One of the authors of this memoir awarded him his first contract for bridge masonry on the Chicago, Madison & Northern (I. C. R. R.) and he demonstrated then that he was not only a good engineer but a good contractor; a contractor who carried into his new business all of the sense of honor and fair dealing which early training and the ethics of engineering had confirmed in him.

The recognition of these traits by the railroads was soon manifest and he was selected for many building enterprises without competition. He was the type of contractor who was given work on a percentage basis with a well grounded confidence that the work would be done in the best possible manner, on honor. There are masses of well built masonry scattered through many states which will, for ages to come, stand as monuments to the integrity and skill which justified the faith reposed in Frederick S. Brown. He was a loyal friend, a just and true man. He was a consistent member of the Presbyterian Church and in the long period that we have known him our ears have never heard from his lips an oath or an unclean remark.

(Signed) Isham Randolph,
L. G. Curtis.

October, 1917

BOOK REVIEWS

Lubricating Engineer's Handbook, a Reference Book of Data, Tables and General Information for the Use of Lubricating Engineers, Oil Salesmen, Operating Engineers, Mill and Power Plant Superintendents, Machine Designers, etc. By John Rome Battle, B. S. in M. E., 333 pp., 6 by 9 inches, 161 illustrations, tables and charts. Published by J. B. Lippincott Company, Philadelphia.

The amount of lubricants used may in one way be the measure of the industrial life of a country. Friction will quickly stop the most powerful machine, unless the bearing surfaces are properly lubricated. Progress along mechanical lines has been tremendous in the last sixty or seventy years, and, strange to say, that period corresponds almost exactly with the time we have appreciated the value of petroleum products for lubrication.

Having in mind the large number of lubricants, petroleum and otherwise, as well as the diversified machines in use, there seems to be a real field for such a book as the Lubricating Engineer's Handbook. The designing engineer is interested in the subject of theoretical lubrication and its effect upon the design of machinery bearings. Operating engineers are interested in the efficient and smooth-running of the machines under their charge. Owners and managers are interested in reducing cost of production and lengthening the life of the machinery. Purchasing agents want to be posted on the buying of lubricants suitable for use in their plants at the lowest price consistent with the quality and physical requirements. Salesmen must have a general knowledge of working conditions in the various industries, as well as of the manufacture and properties of various lubricants. The manufacturer of the lubricants knows that his business depends on customers obtaining materials meeting their requirements exactly.

To all these this book is valuable. Some may hastily verify their own ideas, while others will find valuable suggestions. The book is not technical, and yet it covers the field most thoroughly. It is divided into logical sections: First, descriptions of the various oils, greases and lubricants, manner of testing, etc.; second, bearing lubrication, showing the different kinds of bearings and the particular problems attending each; third, descriptions ot various machines, in various lines of manufacture, from air compressors to wire drawing machinery, with many suggestions, recommendations and ideas looking to better service with the machines in use and for the use of the most suitable lubricant for each purpose.

A most complete index makes it easy to refer to any subject or process, while an appendix contains much valuable general information.

C. A. M.

Preliminary Mathematics. By Prof. F. E. Austin, B. S., E. E. 169 pages, 5 in. by 7½ in., bound in cloth. Price, $1.20. Published by the author at Hanover, N. H.

The ultimate aim of mathematical study being to obtain a practical knowledge of numbers and to discipline the mental powers, it is evident that the book which best assists the student is that one which is comprehensive in principles and extensive in details. But "mathematics" covers such a range, from arithmetic to calculus, from addition to variables, that the small volume either takes too much for granted, touching only the prominent points, or devotes too much space to the simpler operations.

In this book the author has attempted to span the entire range of preliminary mathematics, from the simplest notation, through arithmetic, decimals, fractions and elementary algebra. His idea has been to collect the various principles of mathematics, show their inter-relation, and explain in detail the basis of operations.

About one-half of the book is of especial value to pupils up to and including the eighth grade, while the latter half will be of assistance to pupils in the high school. A valuable feature is the inclusion of the examination questions in algebra, mathematics, etc., for various schools and colleges.

C. A. M.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings.

Meeting No. 977, October 8, 1917.

This was a regular meeting of the Society and was called to order about 8 p. m. by President Burt, with forty-five members and guests present.

In accordance with the Constitution the Secretary read the proposed amendments to the Constitution amending Article IV, Admissions; VI, Officers; VII, Nomination and Election of Officers, (A) Providing for a Nominating Committee and Rotation of Names on the Ballot; (B) Providing for Rotation of Names on the Ballot; VIII, Duties of Officers and Committees; XI, Meetings; XIV, Miscellaneous.

The subject for the evening was "Fire Prevention," and the President introduced the first speaker of the evening, Mr. William C. Robinson, Vice-President of the Underwriters Laboratories. Mr. Robinson presented his paper on "Building Column Tests." These tests are being made on full size columns, under conditions as near as possible to what would be found in case of fire in a modern building. Several lantern slides were shown of the tests and an invitation was given the members of the Society to visit the Laboratories and see the tests made.

Mr. Henry M. Byllesby was then introduced by the President and made an eloquent appeal for the members of the Society to support the Second Liberty Loan.

The President introduced Mr. Frank D. Chase, Architect, who gave a most interesting discussion of the "Economics of Fire Prevention," calling attention to the excessive and unnecessary burden laid on the people by fire losses approximating one million dollars a day. The engineer, in the speaker's opinion, can do much in the way of design and construction to both prevent fire and protect against fire.

Mr. C. W. Hejda, Chief Engineer, Bureau of Fire Prevention and Public Safety of the Chicago Fire Department, read a carefully prepared paper on "Fire Prevention Work of the Chicago Fire Department," accompanying the same with a moving picture entitled, "The Unbeliever Convinced." The speaker called attention to the improvements in methods of fighting fires, as well as to methods of preventing them starting.

The meeting adjourned at 10:30 p. m.

Meeting No. 978, October 15, 1917.

A meeting of the Hydraulic, Sanitary and Municipal Section was called to order at 8:00 p. m. by President Burt, with about fifty members and guests present.

The president introduced the speaker of the evening, Mr. Herbert E. Hudson, who read a paper on the "Construction Features of the Argyle Street Sewer System." This paper was illustrated by lantern slides, and gave the story of the work from start to finish, with many interesting details of design, construction and cost. Messrs. Green, Sherman, Burke and others took part in the discussion which followed.

The Secretary read the proposed revised rules for the Hydraulic, Sanitary and Municipal Section of the Society.

The meeting adjourned at 10:10 p. m.

Meeting No. 979, October 22, 1917.

A joint meeting of the Electrical Section of the Society and the Chicago Section of the American Institute of Electrical Engineers was called to order at 8:00 p. m., with 210 members and guests present.

The Vice-Chairman of the Electrical Section, Mr. L. L. Perry, introduced Lieutenant-Colonel L. D. Wildman, Chief Signal Officer of the Central Divi-

sion, U. S. A., who delivered a most interesting address on the "Engineering Problems of the Signal Corps." He explained the various branches of the service, describing the construction and maintenance of submarine cables, normal land lines of communication, battle fire communication, fire control and aeronautics in all its branches, including captive and dirigible balloons, and aeroplanes.

Lieutenant-Colonel Wildman's address was followed by a moving picture entitled "Who Leads the National Army." This picture was arranged by Mr. Wharton Clay for the National Training Camps Association, and illustrated the work of the camps in a most effective manner. The future officers were shown at work and at play, from the many amusements possible in camps of this character, to battalion drill, and included setting-up exercises, marching, bayonet drill, etc.

The meeting adjourned at 10:00 p. m.

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WAR SERVICES

All members of the Western Society of Engineers who are in the service of any branch of the army or navy, either as commissioned officers or otherwise, or are engaged in civilian work for any branch of the government due to the war, are requested to notify the undersigned promptly in order that a complete record may be kept of the services rendered to the Government by the Society membership.

The Society will also be glad to receive the photographs of all its members who are in service. An album will be prepared so these can be kept in the Library of the Society.

EDGAR S. NETHERCUT, Secretary.

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ELECTRIC WAVES

By W. S. Franklin and Barry McNutt.***

Presented May 28, 1917.

One of the most important items of needed improvement in the curriculum of the engineering school is the rejuvenation of the usual dried-up and unfruitful course in theoretical mechanics, and this discussion of the simplest aspects of the dynamics of wave motion (and the discussion is almost wholly mechanical) is intended to show what can be done to make this important branch of mechanics intelligible to the engineering student. The consideration of periodic waves has been completely excluded in order that the discussion may be vividly physical throughout.

Let no would-be reader be frightened at the forbidding array of partial differentials in this paper, for the paper contains little beyond the simplest kind of arithmetic and the simplest kind of physics, expressed at times though some of it be in terms of the extremely awkward and really hideous notation of the infinitesimal calculus. Any young man who is not afraid of mere notation can understand this paper.

THE EQUATION OF A TRAVELING CURVE

The curve *cc*, Fig. 1, is stationary with respect to the origin of the coordinates O', and the curve and the origin O' are assumed

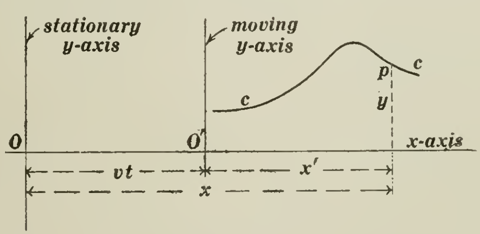

Fig. 1. The Equation of a Traveling Curve.

to be traveling together towards the right at velocity v so that the abscissa of the moving origin O' as referred to the fixed origin O is

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at each instant equal to vt as indicated in the figure. Therefore the abscissa x of the point p on the moving curve is $x = x' + vt$ so that $x' = x - vt$. Let the equation to the moving curve *cc*, as referred to the moving origin O', be

$$y = F(x')$$

Then, substituting $x - vt$ for x', we have

$$y = F(x - vt) \qquad (1)$$

as the equation of a curve traveling to the right at velocity v; and in a similar manner it may be shown that

$$y = f(x + vt) \qquad (2)$$

is the equation of a curve traveling to the left at velocity v.

It is highly instructive to derive a differential equation which is satisfied by both equations (1) and (2); and, inasmuch as the rules for differentiating are not usually understood by the student, especially when applied to such general equations as (1) and (2), the following discussion is arranged to appeal to one's fundamental arithmetical sense. Awkwardness of notation is the chief difficulty, as usual, and one must remember the following points:

If y increases always u times as fast as x, then u is called the *derivative of y with respect to x*. If y depends on x as the only variable, the derivative is represented by the symbol $\frac{dy}{dx}$. If y depends on more than one variable the derivative with respect to x is called a *partial derivative* and it is usually represented by the symbol $\frac{\partial y}{\partial x}$. The two symbols $\frac{dy}{dx}$ and $\frac{\partial y}{\partial x}$ have, however, precisely the same arithmetical meaning; thus in the first case y actually increases $\frac{dy}{dx}$ times as fast as x, and in the second case y would increase $\frac{\partial y}{\partial x}$ times as fast as x if x only, among all the variables upon which y depends, were allowed to change.

If u ($\frac{dy}{dx}$ or $\frac{\partial y}{\partial x}$) increases w times as fast as x, then, of course, w is the derivative of u with respect to x and, of course, it is represented by $\frac{du}{dx}$ or $\frac{\partial u}{\partial x}$. In thinking of the derivative of u, however, it is often desirable to keep clearly in mind the fact that u itself is the derivative of y with respect to x. This is shown by the following notation:

$$\frac{du}{dx} = \frac{d^2y}{dx^2} \text{ when } u = \frac{dy}{dx}$$

$$\frac{\partial u}{\partial x} = \frac{\partial^2 y}{\partial x^2} \text{ when } u = \frac{\partial y}{\partial x}$$

PARTIAL DIFFERENTIAL EQUATION OF TRAVEL

The two equations 1 and 2, above, are particular solutions of a partial differential equation which may be called the *partial differential equation of travel, namely*

$$\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2} \qquad (3)$$

and this differential equation is of fundamental importance in the mathematical theory of wave motion.

For the sake of simplicity let the quantity $x - vt$ of equation 1 be represented by z so that

$$z = x - vt \qquad (i)$$

from which we have $\frac{\partial z}{\partial x} = 1$ (which means that if x, only increases, z must increase at the same rate) and $\frac{\partial z}{\partial t} = -v$ (which means that if t, only, increases, z must increase $-v$ times as fast, or decrease v times as fast.

Equation 1 is to be thought of for the moment as $y = F(z)$, and the derivative $\frac{dy}{dz}$ may be represented by $F'(z)$, meaning that y increases $F'(z)$ times as fast as z.

PROPOSITION: y increases $F'(z)$ times as fast as z, and when x, only, changes z increases $\frac{\partial z}{\partial x}$ times as fast as x. Therefore when x only changes, y must increase $F'(z)$ *times* $\frac{\partial z}{\partial x}$ *times* as fast as x. Therefore $\frac{\partial y}{\partial x} = F'(z) . \frac{\partial z}{\partial x}$. But $\frac{\partial z}{\partial z} = 1$ as stated above. Therefore *

$$\frac{\partial y}{\partial x} = F'(z) \qquad (ii)$$

*To the student who is familiar with the rules for partial differentiation this argument may seem ridiculous, but it is not ridiculous, by any means. No one can understand partial differentiation who has not at some time followed this kind of an argument in pure arithmetic.

Proposition y increases $F'(z)$ times as fast as z, and when t, only, changes z increases $\dfrac{\partial z}{\partial z}$ times as fast as t. Therefore when t, only, changes y must increase $F'(z)$ *times* $\dfrac{\partial z}{\partial t}$ *times* as fast as t. Therefore, $\dfrac{\partial y}{\partial t} = F'(z) . \dfrac{\partial z}{\partial t}$. But $\dfrac{\partial z}{\partial t} = -v$ as stated above. Therefore,

$$\frac{\partial y}{\partial t} = -v . F'(z) \qquad (iii)$$

From equations (ii) and (iii) it is evident that $\dfrac{\partial y}{\partial t} = -v . \dfrac{\partial y}{\partial x}$ and this may be called the differential equation of travel to the right. If we had started with $y = f(x + vt)$ and $z = x + vt$, the above discussion would have led to $\dfrac{\partial y}{\partial t} = +v . \dfrac{\partial y}{\partial x}$ which may be called the differential equation of travel to the left. Neither of these differential equations is of importance in the theory of wave motion.

Let us think of the function of $F'(z)$ as changing $F''(z)$ times as fast as z.

When x, only, changes z changes $\dfrac{\partial z}{\partial x}$ times as fast as x, and therefore $F'(z)$ changes $F''(z)$ *times* $\dfrac{\partial x}{\partial z}$ *times* as fast as x. But $F'z$ is equal to $\dfrac{\partial y}{\partial x}$, according to equation *ii*. Therefore $\dfrac{\partial y}{\partial x}$ increases $F''(z)$ *times* $\dfrac{\partial z}{\partial x}$ *times* as fast as x. Therefore, since $\dfrac{\partial z}{\partial x} = 1$, we have

$$\frac{\partial^2 y}{\partial x^2} = F''(z) \qquad (iv)$$

When t, only, changes z changes $\dfrac{\partial t}{\partial z}$ times as fast as t, there-

fore $F'(z)$ increases $F''(z)$ *times* $\frac{dt}{\partial z}$ *times* as fast as t, and, therefore, $-v.F'(z)$ increases $-vF''(z)\frac{\partial z}{\partial t}$ times as fast as t. But $-v.F'(z)$ is equal to $\frac{\partial y}{\partial t}$, according to equation *iii*. Therefore $\frac{\partial y}{\partial t}$ increases $-v \times F''(z) \times \frac{\partial z}{\partial t}$ times as fast as t, and, therefore, since $\frac{\partial z}{\partial t} = -v$, we have

$$\frac{\partial^2 y}{\partial t^2} = v^2 F''(z) \qquad (v)$$

From equations (iv) and (v) we have

$$\frac{\partial^2 y}{\partial t^2} = v^2 . \frac{\partial^2 y}{\partial x^2} \qquad (3)$$

and this same result would be obtained from equation 2 by taking $z = x + vt$. That is to say, equation 3 is a differential equation which is satisfied by both of the equations 1 and 2, and it is of very great importance in the mathematical theory of wave motion.

THE PRINCIPAL OF SUPERPOSITION. A PROPERTY OF LINEAR DIFFERENTIAL EQUATIONS.

A principle of extremely wide application in physics is the so-called principle of superposition. From the physical point of view

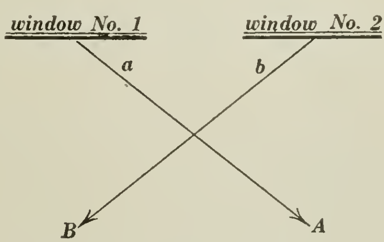

Fig. 2. Two Beams of Light Through the Same Region.

a general statement of the principle is scarcely possible, and therefor the following examples must suffice:

(1) A person at A in Fig. 2 can see window No. 1 and another at B can see window No. 2 *at the same time*. This means that the two beams of light a and b can travel through the same region at the same time without getting tangled together, as it were; each

beam behaves as if it were traveling through the region alone. (2) Two sounds can travel through the same body of air simultaneously, and each sound travels as if it occupied the space by itself. (3) Two systems of water waves can travel over the same part of a pond simultaneously, each system behaving as if the other were not present. (4) Two messages* can travel over a telegraph wire simultaneously and not get mixed up together. (5) Two forces F and G exerted simultaneously upon an elastic structure produce an effect which is the sum of the effects which would be produced by the forces separately, provided the sum of the forces does not exceed the elastic limit of the structure, therefore, each force may be thought of as producing the same effect that it would produce if acting alone.

All of the effects in physics which are superposable—and this includes by far the greater portion of the effects in mechanics, heat, electricity and magnetism, light and sound, and chemistry—are expressible in terms of linear differential equations, and the principle of superposition is a clearly defined property of such equations as follows: *If y is a function of x which satisfies a linear differential equation, and if z is another function of x which satisfies the same differential equation, then $(y+z)$ is a function which satisfies the differential equation.*

This proposition is true for both ordinary and partial linear differential equations, and indeed nearly all of the superposable effects in physics are expressible in terms of partial linear differential equations. The proof of the proposition is, however, nearly the same for ordinary and for partial differential equations, and therefore it is sufficient to give the proof for ordinary differential equations only. Let the given linear differential equation be:

$$u + A\frac{du}{dx} + B\frac{d^2u}{dx^2} + \text{———} = 0 \qquad (i)$$

Let y be a function of x which satisfies the differential equation, then:

$$y + A\frac{dy}{dx} + B\frac{d^2y}{dx^2} + \text{———} = 0 \qquad (ii)$$

Let z be another function of x which satisfies (i) then

$$z + A\frac{dz}{dx} + B\frac{d^2z}{dx^2} + \text{———} = 0 \qquad (iii)$$

Now $\dfrac{d(y+z)}{dx} = \dfrac{dy}{dx} + \dfrac{dz}{dx}$ and $\dfrac{d^2(y+z)}{dx^2} = \dfrac{d^2y}{dx^2} + \dfrac{d^2z}{dx^2}$.

*Indeed any number of distinct messages can travel over a telegraph wire in either direction or in both directions simultaneously. The only limiting feature in multiplex telegraphy is the design of the sending and receiving apparatus; and the same is true in wireless telegraphy. In each of the above examples the word *two* means *two or more.*

Therefore adding equations *ii* and *iii*, we get:

$$(y+z)+A\frac{d(y+z)}{dx}+B\frac{d^2(y+z)}{dx^2}+\text{-----}=0 \qquad (iv)$$

But equation *iv* is exactly the same form as equation *i and therefore* $(y+z)$ *is a function of x which satisfies equation i**.

The above proposition is the basis of Fourier's method of analysis as applied to the flow of heat and as applied to the motion of strings, and it is the basis of the use of spherical, zonal and cylindrical harmonics. The importance of the proposition can scarcely be over-estimated.

UNDETERMINED CONSTANTS IN THE SOLUTION OF AN ORDINARY DIFFERENTIAL EQUATION.

It is sufficient, perhaps, to illustrate this matter by two very simple examples.

Example 1. Consider the simple ordinary differential equation

$$\frac{dy}{dt}=a$$

where a is a given constant. The increase of y during t seconds is at, and the value of y at the end of t seconds is

$$y=at+C$$

where C is the unknown value of y at the beginning $(t=0)$.

Example 2. Consider the simple ordinary differential equation

$$\frac{d^2y}{dt^2}=a$$

where a is a given constant. Then

$$\frac{dy}{dt}=at+B$$

and $y=\frac{1}{2}at^2+Bt+C$ where C is the unknown value of y at the beginning, and B is the unknown value of $\frac{dy}{dt}$ at the beginning.

NOTE.—From the point of view of the physicist the unknown constants which appear in the general solution of an ordinary differential equation are thought of as *disposable constants*, because the solution may be made to fit any special case by assigning proper values to these constants. The number of disposable constants in the general solution of an ordinary differential equation is always equal to the order of the differential equation.

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*The above proposition is true for any linear differential equation whatever; that is, when the coefficients A, B, etc., are constanst, and when the coefficients A, B, etc., are functions of the independent variable x. The latter type of linear differential equation does not, however, concern us here.

UNDETERMINED FUNCTIONS IN THE SOLUTION OF A PARTIAL DIFFERENTIAL EQUATION

It is sufficient, perhaps, to illustrate this matter by a few simple examples.

Example 1. Concerning a hill it is only known that its slope, $\frac{\partial y}{\partial x}$, in the direction of the x—axis is constant and equal to a so that

$$\frac{\partial y}{\partial x} = a \qquad (i)$$

Before the complete hill or surface can be constructed from this differential equation an arbitrary starting curve cc, Fig. 3, must be chosen. Let $y = F(z)$ be the equation to the curve cc, then

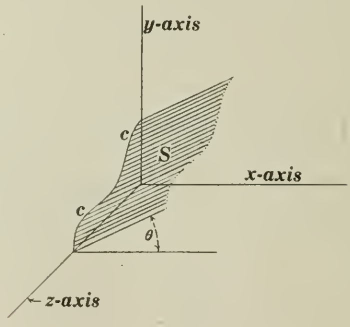


Fig. 3. Development of a Hill or Surface.

$F(z)$ is the height of the hill at any point z on cc, and $ax + F(z)$ is the height of the hill at any point x, z. That is to say, the integration of (i) gives

$$y = ax + F(z) \qquad (ii)$$

Example 2. If all boys were of the same ability we might say that any boy saves money at the average rate of $5 per year beginning at 14 years of age. Integrating with respect to b, the boy, from 14 years to 21 years we get $35; but the amount of money a boy has when he becomes of age is not $35 plus a *constant*, but $35 + $F(m)$, where $F(m)$ is what the boy's "old man" has saved for him; b and m are independent variables, let us say, and a "constant" of integration with respect to b turns out to be an unknown function of m.

Example 3. Concerning a hill it is known only that its slope, $\frac{\partial y}{\partial x}$, in the direction of the x-axis increases a times as fast as x,

or, expressed in symbols, we have

$$\frac{\partial^2 y}{\partial x^2} = a \qquad (iii)$$

Before the complete hill or surface can be constructed from this differential equation, two things must be given, namely (1) An arbitrary starting curve like *cc*, Fig. 3, and (2) an arbitrary value of starting slope, $\frac{\partial y}{\partial x}$, at each point of *cc*.

The integration of *i* or *iii* is called *partial integration*, but example 2 should make it clear that partial integration is identical to ordinary integration, the only difference being that in the former the "constant" of integration turns out to be a function of the other independent variable or variables. Therefore, integrating *iii* twice we get

$$y = \tfrac{1}{2}\, ax^2 + x . f(z) + F(z) \qquad (iv)$$

where $f(z)$ and $F(z)$ are unknown functions of z. Indeed, $y = F(z)$ is the equation to the starting curve *cc* in Fig. 3, and the value of the starting slope $\left(\frac{\partial y}{\partial x}\right)_{x=o}$ at each point of *cc* is $\left(\frac{\partial y}{\partial x}\right)_{x=o} = f(z)$.

Note.—From the point of view of the physicist the unknown functions which appear in the general solution of a partial differential equation are thought of as *disposable functions*, because the solution may be made to fit any special case by properly choosing the forms of these functions. The number of these disposable functions in the general solution of a partial differential equation is always equal to the order of the differential equation.

General solution of equation 3. Equations 1 and 2 are particular solutions of 3 and, therefore,

$$y = F(x - vt) + f(x + vt) \qquad (4)$$

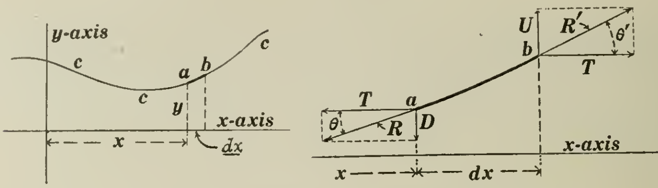
is also a solution, according to the principle of superposition. But equation 4 involves two independent and disposable functions and it is, therefore, the general solution of 3.

Equation 4 represents the piling on top of each other of two curves of any shape, one of the curves traveling to the right at velocity v, and the other traveling to the left at velocity v.

DIFFERENTIAL EQUATIONS OF MOTION OF A STRETCHED STRING

When a stretched string is in equilibrium it is, of course, straight. Let us choose this equilibrium position of the string as the x-axis of reference. We will assume that each particle of the string moves in a direction at right angles to the string (parallel to y-axis of reference), and we will assume that the string is perfectly flexible, which means that the only forces to be considered are the forces due to the tension of the string. An important consequence of the first assumption is that the x-component of the tension of

the string has always and everywhere a certain value T which is equal to the tension of the string when it is in equilibrium.



Figs. 4 and 5. Motion of a Stretched String.

Let the curve *ccc*, Fig. 4, be the configuration of the string at a certain instant, that is, *ccc* is what the photographer would call a snap shot of the moving string. The shape of the curve *ccc* defines y as a function of x and the steepness of the curve at any point is the value of $\frac{\partial y}{\partial x}$* at that point.

Consider the very short portion $a\,b$ of the string. The length of this portion when the string lies along the x-axis (in equilibrium) is dx, and the mass of the portion is $m.\,dx$, where m is the mass per unit length of string. An enlarged view of the very short portion ab of the string is shown in Fig. 5. The adjacent portions of the string pull on the portion ab, the pull at a is represented by R and it is parallel to the string at a, and the pull at b represented by R' and it is parallel to the string at b. The x-component of R is the force T to the left, and the x-component of R' is an equal force T towards the right. Therefore, the downward force D (see Fig. 5), is equal to $T \tan \theta$, the upward force U is equal to $T \tan \theta'$, and the net upward force acting on the portion ab of the string is:

$$dF = U - D = T \tan \theta' - T \tan \theta \qquad (i)$$

But $\tan \theta$ is equal to the value of $\frac{\partial y}{\partial x}$ at a, and $\tan \theta'$ is equal to the value of $\frac{\partial y}{\partial x}$ at b. Therefore, the value of $\tan \theta' - \tan \theta$ is the increase of $\frac{\partial y}{\partial x}$ from a to b, and this increase is equal to $\frac{\partial^2 y}{\partial x^2}.dx$.

*Any reader who fails to appreciate the fact that we are here talking about the state of affairs at a given instant, or that time is supposed to stop, as it were, may wonder why we use the notation $\frac{\partial y}{\partial x}$ instead of $\frac{dy}{dx}$.

This is evident when we consider that $\frac{\partial^2 y}{\partial x^2}$ means the rate of increase of $\frac{\partial y}{\partial x}$ with respect to x. Therefore, substituting $\frac{\partial^2 y}{\partial x^2}.dx$ for $\tan\theta' - \tan\theta$ in equation (i) we get:

$$dF = T\frac{\partial^2 y}{\partial x^2}.dx \qquad (ii)$$

Now, according to Newton's law of motion, the net upward force dF acting on the portion ab of the string is equal to the mass $m.dx$ of the portion multiplied by the upward acceleration, $\frac{\partial^2 y}{\partial t^2}$, of the portion. Therefore substituting $m\frac{\partial^2 y}{\partial t^2}.dx$ for dF in equation ii we get:

$$m\frac{\partial^2 y}{\partial t^2} = T\frac{\partial^2 y}{\partial x^2}$$

or

$$\frac{\partial^2 y}{\partial t^2} = \frac{T}{m}.\frac{\partial^2 y}{\partial x^2} \qquad (3) \quad bis.$$

The general solution of this differential equation, as explained above, is

$$y = F(x - vt) + f(x + vt) \qquad (4) \quad bis.$$

where v is given by the equation:

$$v\sqrt{\frac{T}{m}} \qquad (5)$$

Of course, particular solutions of equation 3 are

$$y = F(x - vt) \qquad (6)$$

and

$$y = f(x + vt) \qquad (7)$$

Equation 6 represents a bend or curve on the string traveling to the right at velocity v and retaining its shape unchanged, and equation 7 represents a bend or curve on the string traveling to the left at velocity v and retaining its shape unchanged. These traveling bends of unchanging shape are called pure waves.

PURE WAVE TRAVELING TO THE RIGHT

Equation 6 expresses what is called a *pure wave* traveling to the right and it is important to consider the necessary relation between V and s, where V is the sidewise velocity and s is the slope of the string at a point; of course, $V = \frac{\partial y}{\partial t}$ and $s = \frac{\partial y}{\partial x}$.

From equation 6 we have $s = \frac{\partial y}{\partial x} = F'(x - vt)$, and

$V = \dfrac{\partial y}{\partial t} = -v.F'(x - vt)$, and, therefore, for a pure wave traveling to the right we have

$$\frac{V}{s} = -v \qquad (8)$$

PURE WAVE TRAVELING TO THE LEFT

From equation 7 we have $s = \dfrac{\partial y}{\partial x} = F'(x + vt)$ and

$V = \dfrac{\partial y}{\partial t} = + v.F'(x + v)$ and, therefore, for a pure wave traveling to the left we have $\dfrac{V}{s} = + v \qquad (9)$

REFLECTION AND CHANGE OF PHASE THEREBY

Let us consider a simple form of pure wave traveling to the right along a string, a wave throughout which the sidewise velocity of the string has everywhere the same value V, and throughout which the slope of the string has everywhere the same value s. Such a simple wave we will call a *ribbon wave,* and it may be symbolized by the arrow in Fig. 6. The head of the arrow shows the direction of travel, everywhere between the points a and b the string is moving sidewise at velocity V, and everywhere between a and b the slope of the string is s. This slope is not actually shown, however.

Figs. 6 and 7. Reflection from Rigid End of String.

What happens when the wave $V\ s$ reaches the end of the string? Whatever happens on the string it must be of the nature of a pure wave traveling to the right and a pure wave traveling to the left, one heaped on top of the other, because this is the physical interpretation of the general equation 4. Therefore, if we assume a pure wave (sidewise velocity V' and slope s') to shoot to the left from E when ab reaches E we are sure to cover every possible outcome, and then if this assumption is justified by showing that it satisfies all of the necessary conditions, we may be sure that the correct solution has been found. In Fig. 7, therefore, is shown the tail end of the original wave $V\ s$, and the beginning of an assumed reflected wave $V'\ s'$. Now, according to equations 8 and 9 we must

have $\dfrac{V}{s} = -v$ (*i*)

and $\dfrac{V'}{s'} = +v$ (*ii*)

Furthermore the actual end of the string cannot move and, therefore, we must have

$V + V' = O$ (*iii*)

and from equations *i, ii* and *iii* it follows that $V' = -V$ and that $s' = s$. That is to say, a wave is wholly reflected from the rigid end of a string (numerical values of V' and V the same, and numerical

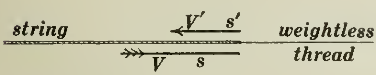


Fig. 8. Reflection from Free End of String.

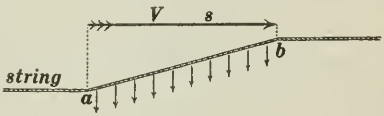


Fig. 9. Complete Picture of a Ribbon Wave.

values of s and s' the same), and the sidewise velocity of the string in the reflected wave is the reverse of the sidewise velocity of the string in the original wave ($V' = -V$).

Figure 8 represents an ideal condition in which the end of a string is held by an indefinitely long weightless thread. In this case the actual end of the string cannot slope and, therefore, we must have

$s + s' = O$ (*iv*)

which in conjunction with equation *i* and *ii* gives

$s' = -s$ and $V' = V$.

That is, a wave is wholly reflected (numerical values of s and s' the same, and numerical values of V and V' the same) at the "free" end of a stretched string, and the slope in the reflected wave is opposite to the slope in the original wave ($s' = -s$). The "free" end of a stretched string as shown in Fig. 8 is merely an ideal, but the analogous condition in electric waves and in air waves is very common.

EXAMPLES OF WAVE MOTION ON A STRING

(1) A complete picture of a ribbon wave traveling to the right on a stretched string is shown in Fig. 9. The region *a b* occupied by the wave has a uniform slope *s*, and every part of the string *ab* is moving downwards at velocity *V* as indicated by the small parallel arrows.

(2) An infinitely long stretched string is struck sharply by a square-faced hammer so as to set every particle of the portion *a b* of the string moving sidewise at a given velocity *V*, as indicated by the small parallel arrows in Fig. 10. To determine the motion of the string it is only necessary to resolve the uniform sidewise velocity and zero slope of portion *a b* into two oppositely traveling

pure waves, as indicated in Fig. 11, in which the arrow A represents a pure ribbon wave traveling to the right and the arrow B represents a ribbon wave traveling to the left. Half of the given sidewise velocity is associated with each ribbon wave, as indicated, and equal and opposite slopes (according to equations 8 and 9) are associated with the respective ribbon waves. The state of affairs a moment later is shown in Fig. 12, and Fig. 13 shows the state of affairs

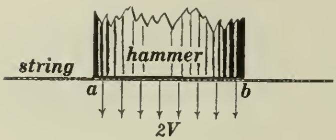


Fig. 10. String Struck by a Square-faced Hammer.

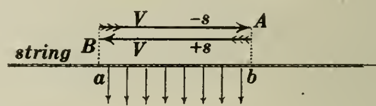
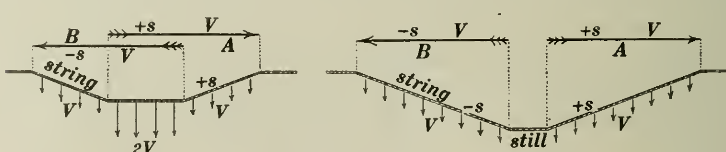


Fig. 11. Effect of Blow on Stretched String.

after the two ribbon waves *A* and *B* have entirely separated from each other.

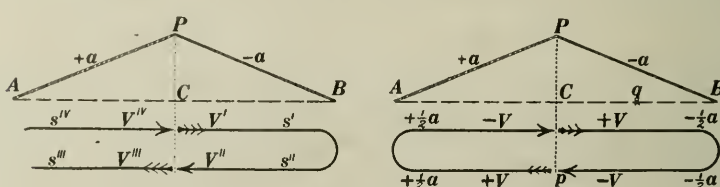
(3) Motion of a plucked string. A stretched string is pulled sidewise into the position *APB*, Fig. 14, and released; and it is



Figs. 12 and 13. Condition After Ribbon Waves Have Separated

required to determine the motion of the string. For the sake of simplicity the point *P* (or *C*) is taken at the middle of the string.

To determine the motion of the string the initial condition of the string, namely, slope $+a$ between *A* and *C*, and slope $-a$ between *C* and *B*, with no sidewise velocity anywhere, must be resolved into pure waves traveling to right and left. Thus the slope



Figs. 14 and 15. Motion of a Plucked String.

$-a$ is resolved into the two waves $s^{1}\,V^{1}$ and $s^{11}\,V^{11}$, and the slope $+a$ is resolved into the two waves $s^{111}\,V^{111}$ and $s^{iv}\,V^{iv}$.

Now V^{1} must be equal to $-V^{11}$ because there is zero sidewise velocity between *C* and *B*, therefore, according to equations 8 and 9,

s^{1} must be equal to s^{11} and the same in sign. But $s^{1} + s^{11} = -a$ so that $s^{1} = s^{11} = -a/2$.

Similarly, V^{111} must be equal to $-V^{iv}$, so that s^{111} must be equal to s^{iv} and the same in sign. But $s^{111} + s^{iv} = +a$, so that $s^{111} = s^{iv} = +a/2$.

Therefore, using $a/2$ for the common numerical value of s^{1}, s^{11}, s^{111} and s^{iv}, and using V for the common numerical value of V^{1}, V^{11}, V^{111} and V^{iv}, and indicating the proper sign in each case, we may simplify Fig. 14 as indicated in Fig. 15.

To find the state of affairs after lapse of time t it is only necessary to consider that the ribbon waves will all have traveled for-

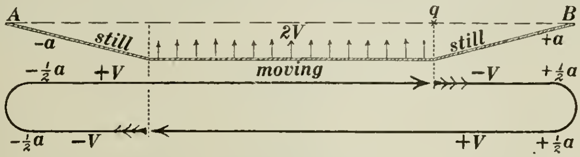


Fig. 16. Plucked String After ⅝ of a Cycle.

wards a distance vt, and that reflection at A and B always takes place with reversal of V. Thus after time sufficient for waves to travel over 1¼ times the length of the string (arrow head p, Fig. 15, will have traveled to A and back to q, and $-V$ will have been converted into $+V$ by reflection at A), the state of affairs will be as shown in Fig. 16. The portion AD of the string is still and its slope is $-a$; the portion DE of the string is moving upward at velocity 2V and its slope is zero; and the portion EB of the string is still and its slope is $+a$. Slope and velocity of each part of string in Fig. 16 is found by adding slopes and velocities associated with the overlapping portions of the respective ribbon waves.*

THE KELVIN LADDER

A number of equidistant bars are fixed to a fine steel wire or ribbon and suspended from a small crank as indicated in Fig. 17. The rotatory motion of each portion of this arrangement satisfies the equation

$$\frac{\partial^2\phi}{\partial t^2} = \frac{E}{k} \cdot \frac{\partial^2\phi}{\partial x^2}$$

where ϕ is the angular displacement at the instant t of the bar which is at a distance x below the upper end of the ladder (x=axis directed downwards), k is the moment inertia of unit length of the ladder, and E is the torque required to produce one radian of twist per unit length of the ladder. This equation may be established by an argument which is nearly identical in form to the argument leading to

*A more elaborate example of the motion of a plucked string as analyzed by this same method is given in the Journal of the Franklin Institute, Vol. CLXXIX, May, 1915.

equation 3 and what we may call a ribbon wave may be symbolized by the arrow in Fig. 17. Every portion of the ladder between the points a and b is rotating at uniform spin-velocity, and the whole of the portion ab of the ladder is uniformly twisted. Let w be the spin-velocity and h the degree of twist (radians per unit length of ladder). Then the ratio w/h has a certain value, a, which is positive or negative, according to whether the wave is traveling upward or downwards.

When a ribbon wave is reflected at the free end B of the ladder, the twist h is reversed without change of sign of w. That is to say, if the ladder is twisted like a right-handed screw or helix in the original wave, it will be twisted as a left-handed screw or helix in

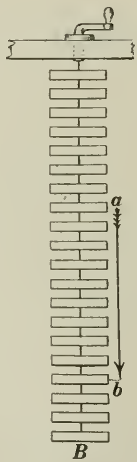


Fig. 17. The Kelvin Ladder.

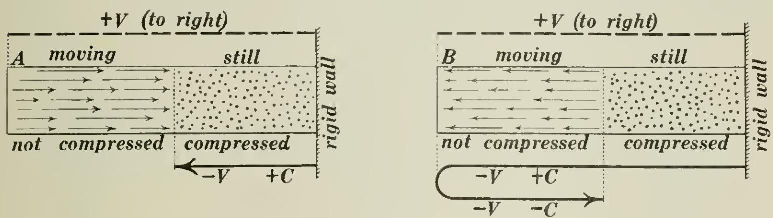
the reflected wave, but the rotation or spin in the reflected wave will be in the same direction as the rotation or spin in the original wave.

When the end bar at B is rigidly fixed, a ribbon wave is reflected at B with reversal of rotation or spin, but without reversal of twist.

What takes place when an elastic rod strikes endwise against a rigid wall and rebounds? A longitudinal wave on a rod is a state of endwise compression C (negative value of C means tension) associated with a certain velocity V of the material of the rod, and the ratio V/C has a certain value, a, which is positive or negative, according to the direction of travel of the wave. The initial condition of the elastic rod just before it strikes the wall is a uniform velocity of the material of the rod towards the wall, this initial condition is to be thought of as always being in existence, except in so far as it is modified by the superposition of new

conditions, and this initial condition of uniform unchanging motion is symbolized by the heavy dotted line in Figs. 18 and 19.

After the rod strikes the wall it continues for a definite time to push steadily against the wall, a long-drawn-out ribbon wave continues to shoot out from the wall as indicated by the heavy-line arrow in Figs. 18 and 19. The first lap of this ribbon wave (velocity $-V$ of the material of the rod, and an associated compression C)



Figs. 18 and 19. Motion of an Elastic Rod Against Rigid Wall.

annuls or literally wipes out the initial velocity V of the rod, and lays down a condition of uniform compression as indicated in Fig. 18. The second lap of the ribbon wave (velocity $-V$ and compression $-C$, because reflection at the free end B of the rod takes place with reversal of C so that the compression in the first lap becomes tension in the second lap) then wipes out the uniform compression and lays down a uniform condition of reversed motion as indicated in Fig. 19. Therefore, when the second lap of the ribbon wave reaches the wall the entire rod is relieved of compression and it is moving away from the wall at velocity V.

SUDDEN STOPPING OF FLOW OF WATER IN A RIGID PIPE

When a valve is suddenly closed at the end of a pipe the stoppage and rebounding of the column of moving water takes place precisely in the manner of the stoppage and rebounding of the rod as represented in Figs. 18 and 19, on the assumption that the pipe is rigid.

EXPERIMENT WITH A CAST IRON ROD

A short slug moving at velocity $2V$ comes squarely against the end of a rod, as indicated by diagram A in Fig. 20. Let us assume that slug and rod are of the same diameter and made of the same material. Then as long as the slug pushes on the rod it may be thought of as a part of the rod, and the state of affairs as shown in diagram A is resolvable into two oppositely moving waves (ribbon waves) $V - C$ and $V + C$ as shown. The wave $V - C$ merges into $V + C$ as it is reflected from the free end of the slug, and soon a ribbon wave of length $2L$ (where L is the length of the slug) develops and travels to the right along the rod as indicated in diagrams B and C. This ribbon wave is reflected from the right-hand end of the rod as indicated in diagram D, a region of doubled velocity $2V$ and zero compression develops until the ribbon wave is half

reflected, as shown in diagram *E*, and then a region *R* of tension begins to develop as indicated in diagram *F*. This tension is equal to the original compression, and, if the rod is made of cast iron, which withstands very great compression, but which does not withstand great tension, it may easily be that the rod separates in the narrow region *R* in diagram *F*. The imperfect elasticity and lack of homogeneity of a cast iron rod modifies the ideal action as represented in Fig. 20, and some appreciable time is required for the cast iron rod to separate in the region *R*. Therefore the slug which

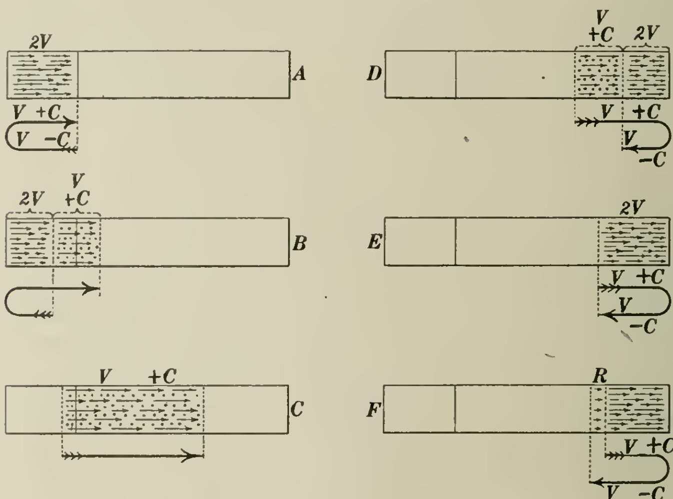


Fig. 20. Experiment with a Cast Iron Rod.

flies off the end of the cast iron rod is sure to be somewhat longer than the original slug in diagram *A*, and it will be moving as a whole at a lower velocity than $2V$. Nevertheless, it is a very interesting and instructive experiment to shoot a steel slug against the end of a cast iron rod.

Use a No. 10 single-barrel shot gun; use a snugly fitting steel slug about 2 inches long; make the cast iron rod of same diameter as steel slug, with a squarely ground end; and use about half-a-gram of black powder with an empty space of two inches or more between powder and slug. This experiment is suggestively frightful, but in fact, quite safe.

An interesting example of the action which is represented in Fig. 20 is afforded by some experiments which were made at Woolwich, England, to determine the effect of exploding a charge of dynamite, or other high explosives, against a thick plate of steel armor. In some of the experiments a high bulge was formed on the back of the plate, and when the plate was cut open its section was as shown in Fig. 21. A deep dent was formed where the explosion

took place, a layer of steel t was thrown off the other side of the plate, and a hollow space h was left.

EXPERIMENT WITH BILLIARD BALLS

Place a number of billiard balls together in a straight row. Let one ball, two balls, three balls, etc., come against the end of

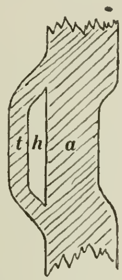


Fig. 21. Effect of a Blow on Armor Plate.

the row, and one ball, two balls, three balls, etc., will fly off from the other end of the row. The action is essentially the same as that shown in Fig. 20.

WHIP ACTION

An interesting modification of the above described experiment of shooting a steel slug against the end of a cast iron rod is to use a tapering cast iron rod and shoot the steel slug against the larger end of the rod. As the ribbon wave travels toward the smaller end of the rod the values of V and C increase, and a much lower initial velocity of slug is sufficient to throw off the tip of the tapered rod.

This wave intensification along a tapered rod is sometimes troublesome in modern high-power guns which taper from breech to muzzle. A quick-acting backward force on the breech-block produces a ribbon wave of tension-and-backward-motion, and as this ribbon wave travels towards the muzzle, it is intensified, and the tension may rise to a value exceeding the strength of the material, thus breaking off the muzzle of the gun, or, what is quite as bad for the gun, leaving a permanent stretch of the muzzle portions of the gun.

The intensification of a wave which travels along a tapered rod is an example of what Prof. P. G. Tait called *whip-action,* and Prof. Tait's explanation of the cracking of a whip is as follows:

First, any object moving through the air at a velocity greater than the velocity of sound produces a sharp snap or crack. Second, a wave of moderate sidewise velocity may be started in the thick and heavy butt portions of a whip, and the sidewise velocity increases more and more as the wave travels towards the small end

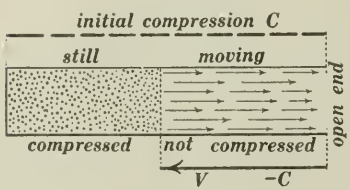
of the whip, thus causing the whip cracker to reach velocities exceeding 1,000 feet per second.

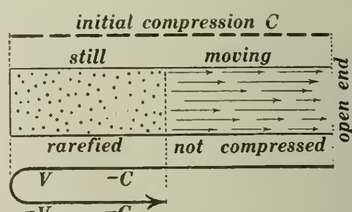
An interesting experiment is to stand on a ladder, hold the butt end of a long flexible whip in the hand, let the whip hang vertically downwards, move the butt quickly to one side, and watch the increasing visible amplitude of motion of the resultant wave as it travels down the whip.*

GUN RECOIL. SIMPLE IDEAL CASE

A portion of the recoil of a heavy gun (backward momentum of gun, the gun assumed to be free) is equal to the forward momentum of the projectile, and the remainder is equal to the forward momentum of the powder gases. The first part of the recoil momentum is quite easily calculated, whereas no rational method has hitherto been developed for calculating the second part of the recoil momentum.**

A very simple and more or less ideal example of gas-recoil would be afforded by suddenly opening one end of a tube which contains very slightly compressed air. The initial condition of uniform compression is symbolized by the heavy dotted line in Figs. 22 and 23 and the heavy arrow symbolizes the long-drawn-out ribbon wave (of outward-motion-and-rarefaction, $+V$ and $-C$), which





Figs. 22 and 23. Example of Gas Recoil.

continues to shoot inwards from the open end of the tube. The first lap of this ribbon wave wipes out the existing compression and lays down a condition of outward motion. The ribbon wave is reflected from the closed end of the tube with reversal of V, and the second lap of the ribbon wave wipes out the outward motion and lays down a condition of rarefaction. The ribbon wave is then reflected from the open end with reversal of C, and the third lap of the ribbon wave wipes out the rarefaction and lays down a condition of inward motion. The ribbon wave is then reflected from the closed end of the tube with reversal of V and the fourth lap of

*Change of wave velocity, due to changing mass and tension, have an important effect here, but it is not worth while to discuss the matter further.

**This deficiency has recently been met in a paper by Wm. S. Franklin, Journal of the Franklin Institute, Vol. CLXXIX, pages 559-577, May, 1915.

the ribbon wave wipes out the inward motion and lays down a condition of uniform compression as at the beginning.

If such a simple wave motion existed in the powder gases of a gun, the gas-recoil momentum would be due to the fact that the gases would continue to push backwards on the breech-block after the opening of the muzzle for the length of time required for the first lap of the ribbon wave to reach the breech-block. As a matter of fact, however, the wave motion in the powder gases is greatly complicated by the velocity already existent in the gases when the muzzle is opened and by the adiabatic cooling of the powder gases as they expand.

EXPERIMENT WITH KELVIN LADDER SHOWING THE EFFECT DESCRIBED IN CONNECTION WITH FIGURES 22 AND 23

Clamp the crank at the top of the ladder, take hold of the bar at the bottom and twist the ladder slightly, and wait for the ladder to become still. Then release the bottom bar. The initial state of twist is analagous to the initial compression of the air in a tube, and

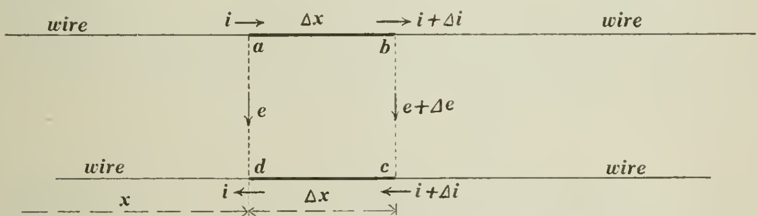


Fig. 24. Wave Motion on a Transmission Line.

the initial twist may be thought of as symbolized by the heavy dotted line in Figs. 22 and 23. Releasing the bottom bar is analagous to the opening of the end of the tube. A ribbon wave (of rotation-and-reversed-twist) then wipes out the existing twist and lays down a condition of uniform rotation. At the instant this ribbon wave reaches the top of the ladder the ladder will be seen to be *flat* (entirely freed from twist) and the entire ladder will be in uniform rotation. The further details of behavior of ladder need not be described, but they should be fully described if the experiment is shown to an audience, otherwise one will not know what to look for.

DIFFERENTIAL EQUATIONS OF ELECTRICAL WAVE MOTION ON A TRANSMISSION LINE

The theory of electrical wave motion is usually developed in terms of electric and magnetic field intensities in space, and the equations are not easy to understand, especially by the electrical engineer who is accustomed to express everything in terms of voltage and current. Therefore, the following discussion of electric wave motion on a transmission line is expressed in terms of voltage and current. Throughout the discussion the resistance of the line

wires is assumed to be negligible and the line wires are assumed to be perfectly insulated.

The horizontal lines in Fig. 24 represent the wires of a transmission line, and *abcd* is an *element* of the line. Let e be the voltage across the transmission line at the point *ad* and let i be "the current in the line at the same point" (meaning outflowing current in one wire and returning current in the other wire) as shown in Fig. 24. The voltage across the line at the point *bc* is $e + \Delta e$, and the current in the line at the same point is $i + \Delta i$.

The capacity of the element *abcd* is $C.\Delta x$, where C is the *capacity of unit length of the line.* Therefore the charge q "on the element" (positive charge on *ab* and negative charge on *cd*) is $q = C.\Delta \times e$,* and the rate of decrease of q, namely, $\frac{\partial e}{\partial t}.C.\Delta x$, is equal to Δi. Therefore we have:

$$C\frac{\partial e}{\partial t} = -\frac{\partial i}{\partial x} \qquad (i)$$

The net electromotive force around the elementary circuit *abcd* is $(e + \Delta e) - e$, and this electromotive force causes the current in the circuit to decrease ** at a definite rate such that

$$\Delta e = -L.\Delta x \times \frac{\partial i}{\partial t},$$

where L is the *inductance per unit length* of the transmission line and $L.\Delta x$ is the inductance of the elementary circuit *abcd*. Therefore we have

$$L\frac{\partial i}{\partial t} = -\frac{\partial e}{\partial x} \qquad (ii)$$

Equations *i* and *ii* contain the two unknown dependent variables e and i, and it is necessary to eliminate one to get an equation involving the other alone. By differentiating equation *i* with respect to t and equation *ii* with respect to x we get

$$C\frac{\partial^2 e}{\partial t^2} = -\frac{\partial^2 i}{\partial x.\partial t} \text{ and } L\frac{\partial^2 i}{\partial t.\partial x} = -\frac{\partial^2 e}{\partial x^2}$$

but $\frac{\partial^2 i}{\partial x.\partial t} = \frac{\partial^2 i}{\partial t.\partial x}$.* and. therefore, we get

*The charge is greater than $C.\ \Delta x \times e$ and less than $C.\ \Delta\ x \times (e + \Delta\ e)$, and when $\Delta\ x$ approaches zero, the expression for q approaches $C.\ \Delta\ x \times e$ as a limit.

**The electromotive force $e + \Delta\ e$ is associated with an electric field from wire to wire and the arrow shows the direction of this field or the direction of $e + \Delta\ e$ as it would be indicated by a voltmeter. Evidently, however, an excessive charge on the wires at *bc* and a large electromotive force from b to c would tend to create a current opposite to i.

$$\frac{\partial^2 e}{\partial t^2} = \frac{1}{LC} \cdot \frac{\partial^2 e}{\partial x^2} \qquad (10)$$

By differentiating equation *ii* with respect to t and equation *i* with respect to x, and eliminating as before, we get

$$\frac{\partial^2 i}{\partial t^2} = \frac{1}{LC} \cdot \frac{\partial^2 i}{\partial x^2} \qquad (11)$$

The general solution of equation 10 is, of course,

$$e = F\,(x - vt) + f\,(x + vt)$$

where
$$v = \sqrt{\frac{1}{LC}} \qquad (12)$$

but it is most convenient for present purposes to consider the two particular solutions $e = F\,(x - vt)$ and $e = f\,(x + vt)$ as follows:

A pure wave traveling to the right in Fig. 24 is represented by the particular solution

$$e = F\,(x - vt) \qquad (13)$$

and to adopt this solution of 10 is to fix the corresponding solution of 11 as follows:

From equations *i* and 13 we have

$$-\,Cv.F'(x - vt) = -\frac{\partial i}{\partial x} \qquad (iii)$$

and from equations *ii* and 13 we have

$$L\frac{\partial i}{\partial t} = -\,F'\,(x - vt) \qquad (iv)$$

Therefore, by integrating *iii* and *iv*, we get

$$i = Cv.F\,(x - vt) + \text{any function of } t \qquad (v)$$

and
$$i = \frac{1}{L\,v}.F\,(x - vt) + \text{ any function of } x \qquad (vi)$$

But, according to equation 12, $Cv = \frac{1}{Lv} = +\sqrt{\frac{C}{L}}$ and, therefore, the unknown function of t in *v* must be identical to the unknown function of x in *vi*, which means, in the most general case, that both functions are constants; and for present purposes these constants may be taken as zero. Therefore equations *v* and *vi* become

$$i = a.F\,(x - vt) \qquad (14)$$

where
$$a = +\sqrt{\frac{C}{L}} \qquad (15)$$

---

*This is by no means self-evident as an arithmetical proposition, but a full discussion of it would be out of place here.

whence by dividing (14) by (13) we get

$$\frac{i}{e} = + a \qquad (16)$$

From equations 13, 14 and 15 it is evident that a pure wave traveling to the right in Fig. 24 is *any distribution of voltage e traveling to the right at velocity v, the current at each point in the line being equal to ae;* or any distribution of current i traveling to the right at velocity v, the voltage across the line at each point being equal to i/a.

A PURE WAVE TRAVELING TO THE LEFT IN FIG. 24

Starting with $e = f\ (x + vt)$ we may find, by an argument similar to the above, that $i = -ae$. That is

$$\frac{i}{e} = - a \qquad (17)$$

and it follows that a pure wave traveling to the left in Fig. 24 is *any distribution of voltage e traveling to the left at velocity v,* the *current at each point in the line being equal to —ae.*

ABOVE DISCUSSION FROM ANOTHER POINT OF VIEW

Prof. P. G. Tait's classical discussion of wave motion on a stretched string which does away with all necessity for the solu-

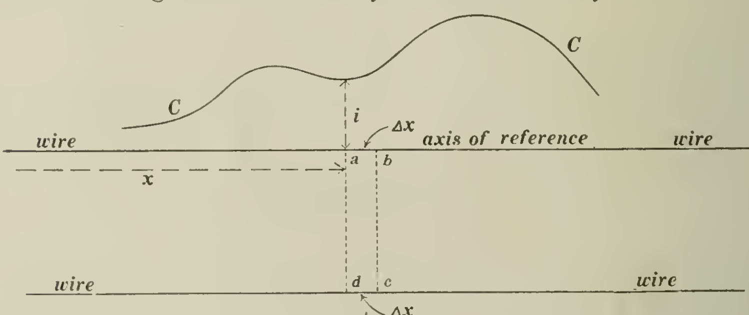


Fig. 25. Effect of Traveling Distribution of Current or Voltage.

tion of differential equations has its analog in the theory of electrical waves, and it is interesting to note that the avoidance of integrations comes from the postulate of travel which is introduced at the start. This fact makes it all the more clear that the classical differential equation of wave motion (see equation 10 or 11 above) is merely a differential equation of travel.

EFFECT OF TRAVELING DISTRIBUTION OF CURRENT

Imagine current to be distributed over a transmission line in any arbitrary manner, the current i at any given point *ad* of the line (meaning outflowing current i in one wire and back-flowing current i in the other wire) being represented by the ordinate i of

any given curve CC, Fig. 25, and suppose this current distribution to travel, as a whole, to the right in Fig. 25 at velocity v, that is to say, let us imagine the curve CC to travel to the right at velocity v and the current distribution to change so as to be represented at each instant by this traveling curve. It is strictly meaningless to think of the current itself as moving along, but it is convenient to think of the current and the magnetic field (also the charges on the wires and the electric field between the wires) as moving along with CC. Such a traveling current distribution would produce a voltage distribution (traveling along with it) such that

$$e = Liv \tag{18}$$

where e is the voltage across the line at the place where the current in the line is i. This equation may be established as follows: The inductance of the element $abcd$ is $L.\Delta x$, and the magnetic flux between the wires ab and cd is equal to the inductance of the element multiplied by the current, everything being expressed in *c. g. s.* units. Now, the current distribution and the associated flux are assumed to travel to the right at velocity v so that all of the flux between ab and cd will sweep across the line bc in $\Delta x/v$ of a second. Therefore the voltage e induced along bc by the traveling flux is $Li.\Delta x$ divided by $\Delta x/v$ which gives Liv abvolts.

EFFECTS OF TRAVELING DISTRIBUTION OF VOLTAGE.

Imagine electric charge to be distributed over the transmission line in Fig. 25 (positive charge on one wire and equal negative charge on the other). This charge means a definite voltage between wires at each point along the line, and we may imagine the voltage e at each point to be represented by the ordinate of a curve CC. Imagine the electric charge and the associated voltage distribution to travel along the line at velocity v. Such a traveling voltage distribution would produce a definite current distribution over the line such that

$$i = Cev \tag{19}$$

where i is the current in the line at the place where the voltage across the line is e and C is the capacity of the line per unit of length. This equation may be established as follows: The capacity of the element $ab\ cd$ is $C.\Delta x$ so that $C.\Delta x \times e$ is the positive charge on ab (or negative charge on cd). But all of the charge on ab must flow past the point b during $\Delta x/v$ of a second, so that the current in the line is found by dividing $C.\Delta x \times e$ by $\Delta x/v$ which gives equation (19). Of course the current distribution travels along with voltage distribution which produces it.

MUTUALLY SUSTAINING CURRENT AND VOLTAGE DISTRIBUTIONS.

Let e, i, and v refer to identically the same quantities in equations 18 and 19 respectively, that is to say, e is produced by the motion of i, and in turn i is produced by the motion of e.

Then equations 18 and 19 are simultaneous equations, and by elimination we get

$$v = \sqrt{\frac{1}{LC}} \qquad (20)$$

and

$$\frac{i}{e} = \pm\sqrt{\frac{C}{L}} \qquad (21)$$

A clear understanding of an electric wave traveling along a transmission line may be obtained from Fig. 26, resistance of line wires being negligible and wires being perfectly insulated. The curve WW corresponds to CC in Fig. 25, and the ordinate y repre-

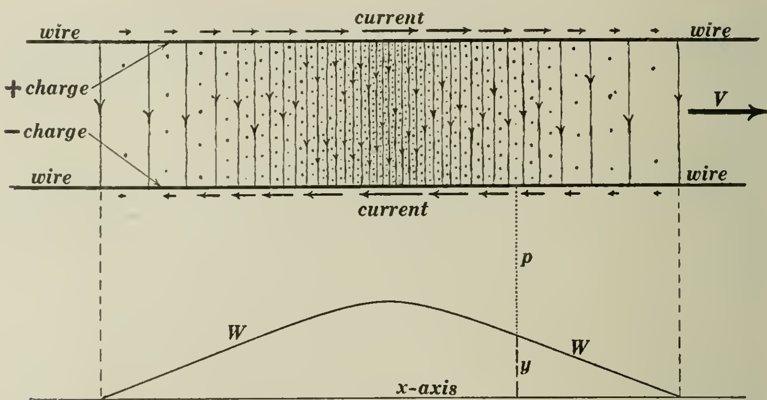


Fig. 26. Showing an Electromagnetic Wave on a Transmission Line.

sents the voltage e across the line or the current i in the line at the point p. The upper wire is positively charged and the fine vertical lines represent the lines of force of the electric field which emanates from the positively charged wire and converges upon the lower wire which is negatively charged. Current flows to the right in the upper wire and to the left in the lower wire as represented by the short horizontal arrows, and, the fine dots represent the lines of force of the magnetic field between the wires, this magnetic field being perpendicular to the plane of the paper in Fig. 26. The heavy arrow V shows the direction of travel of the waves at velocity v.

The directions of travel and the directions of e and i may be correlated as follows: That particular wire is positively charged out of which the electric lines of force emanate; the voltage e is from positively charged wire to negatively charged wire; and *the current in the positively charged wire may be thought of as carrying the positive charge forward from the back of the wave and laying it down on the wire in front of the wave.*

WHAT DETERMINES WAVE FORM?

A device which produces a varying voltage e and which can deliver current *ad libitum* is connected across the end of a trans-

mission line, and the curve (which is of course traveling to the right) which represents the shape of the wave which shoots out along the transmission line is exactly like the curve in Fig. 27 which shows e as a function of the time. This is evident when we consider: First, That the assumed wave, Fig. 28, satisfies the differential equations 10 and 11. Second, That the assumed wave is consistent

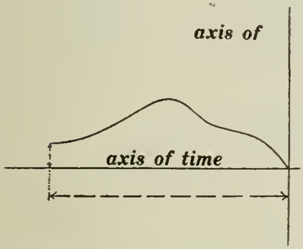


Fig. 27. Showing Voltage e as a Function of the Time.

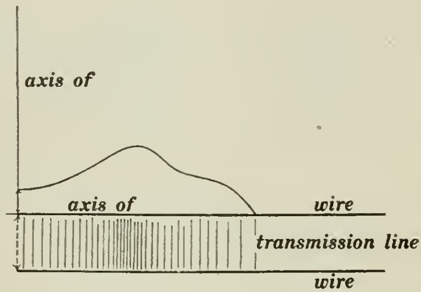


Fig. 28. Showing Shape of Wave which shoots out from End A of a Transmission Line when Voltage e is connected across End of Line.

with the fact that the transmission line is entirely quiescent up to the instant of connecting e, and Third, That the assumed wave in passing out on the line in Fig. 28 involves at each instant a voltage e across the end of the line which is in fact equal to the voltage acting at that instant according to Fig. 27. That is to say, First, the differential equations are satisfied, Second, the initial conditions are satisfied, and Third, the boundary conditions are satisfied.

THE WAVE TRAIN.

When a periodic electromotive force acts across the end of the line; for example, when an alternator is connected to the line; then what is called a *wave-train* passes out along the line, and the state of affairs (before matters are complicated by the reflection of the waves from the distant end of the line) is shown in Fig. 29. This figure shows a wave-train which is produced by a harmonic alternating voltage, and the curve WW is a curve of sines. The short horizontal arrows represent the current at various places in the wires, the fine vertical lines represent the lines of force of the electric field, and the dots represent the lines of force of the magnetic field as in Fig. 26.

THE RIBBON WAVE.

When a battery of constant voltage and negligible resistance is connected across the end of a transmission line, a wave shoots

out on the line, the voltage e in the wave is everywhere of the same value and equal to battery voltage, and the current is everywhere the same in value and equal to $e \times \sqrt{L/C}$, according to equation 16. Such a wave we will call a *ribbon wave*. Thus Fig. 30 represents a ribbon wave d/v seconds after the battery is con-

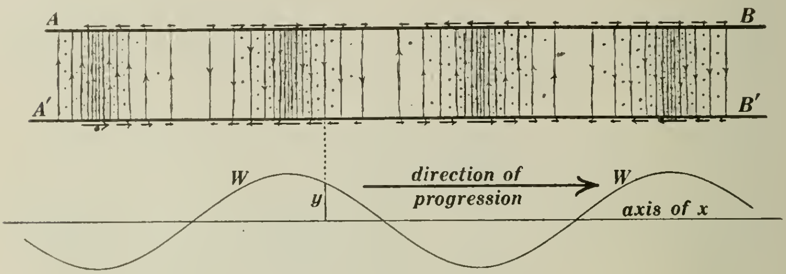


Fig. 29. Wave Train in a Line Before Reflection.

nected. The short horizontal arrows represent current, the fine vertical lines represent the lines of force of the electric field, and dots represent magnetic lines of force as in Figs. 26 and 29.

REFLECTION.

For the sake of brevity and clearness we will discuss only the reflection of the ribbon wave, and such a wave will be represented

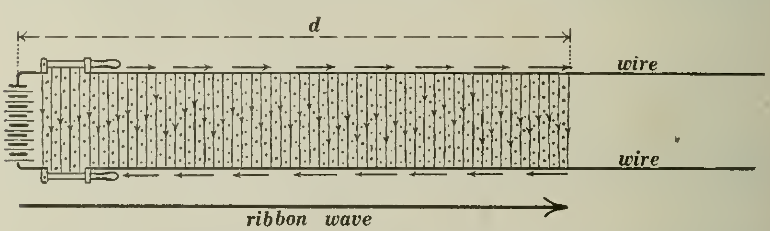


Fig. 30. Showing the Ribbon Wave which Shoots Out from a Battery which is Suddenly Connected to the End of a Line.

by a single heavy horizontal arrow as in Fig. 30. When such a wave is reflected or turned back at the end of a line, the heavy arrow will be shown as turned back as in Figs. 31, 32 and 33. The voltage and current in the original wave are represented by E and I and the voltage and current in the reflected wave are represented by E_r and I_r as shown.

REFLECTION FROM OPEN END OF LINE.

The doubled arrow in Fig. 31 represents a wave which has been turned back or reflected at the open end of a transmission line.

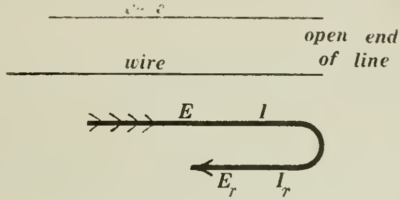


Fig. 31. Showing a Ribbon Wave Partly Reflected from the Open End of a Line.

The necessary condition which must be satisfied at the open end of a line is that the actual current there be zero. Therefore we have:

$$I + I_r = 0 \qquad (i)$$

In addition to this we must have:

$$\frac{E}{I} = +\sqrt{\frac{L}{C}} \qquad (ii)$$

and

$$\frac{E_r}{I_r} = -\sqrt{\frac{L}{C}} \qquad (iii)$$

Now the voltage and current in the original wave are supposed to

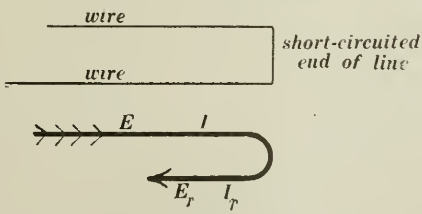


Fig. 32. Showing a Ribbon Wave Partly Reflected from the Short-circuited End of a Line.

be given and the voltage and current in the original wave do, as a matter of course, satisfy equation *ii*. From equation *i* we have:

$$I_r = -I \qquad (iv)$$

and from equations *ii* and *iii* we have:

$$E_r = +E \qquad (v)$$

Reflection at the open end of a line is therefore complete and it takes place with reversal of current.

REFLECTION FROM SHORT-CIRCUITED END OF LINE.

The doubled arrow in Fig. 32 represents a wave which has

been turned back or reflected from the short-circuited end of a line. The necessary condition which must be satisfied at the short-circuited end of a line is that the actual voltage across the end be zero. Therefore we have:

$$E + E_r = 0 \qquad (vi)$$

whence

$$E_r = -E \qquad (vii)$$

and since equations *ii* and *iii* always apply, we get:

$$I_r = +I \qquad (viii)$$

Reflection at a short-circuited end of a transmission line is therefore complete and it takes place with reversal of voltage.

TRANSMISSION LINE OSCILLATIONS WHICH FOLLOW THE SWITCHING ON OF A GENERATOR.

When a generator of negligible resistance and inductance is suddenly switched on to a line, a ribbon wave of generator voltage

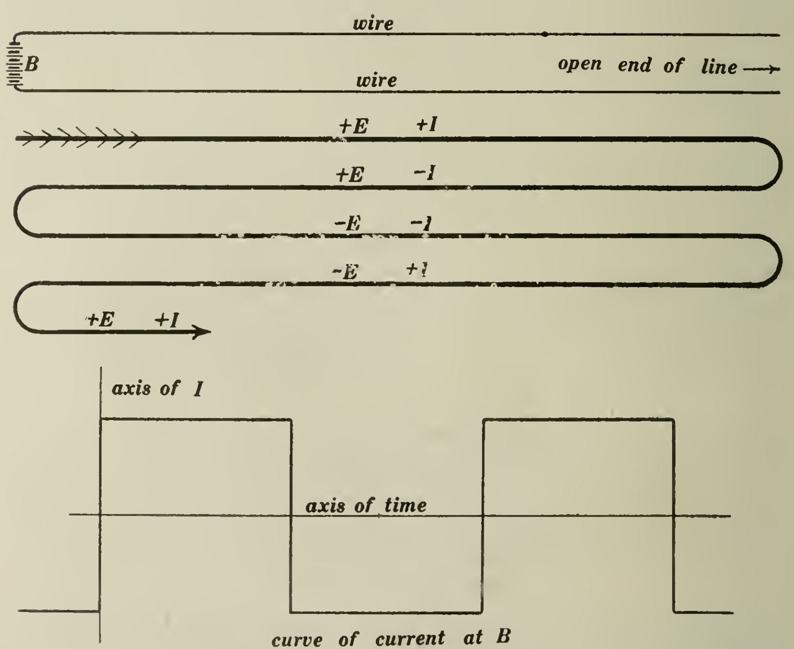


Fig. 33. The upper part of the figure shows a ribbon wave which shoots out from a suddenly connected generator and is repeatedly reflected at both ends of the line. The lower part of the figure shows the value of the current at B as a function of elapsed time.

and corresponding current shoots out over the line. Assuming line resistance to be negligible and line insulation to be perfect, this ribbon wave is reflected back and forth as represented in Figs. 33 and 34, and by adding voltages and currents in the successive laps of

the ribbon wave a precise knowledge of the distribution of voltage and current over the line at any instant may be obtained. Thus, after a thousandth of a second, the total length of the ribbon wave would be 186 miles which would give a definite number of complete

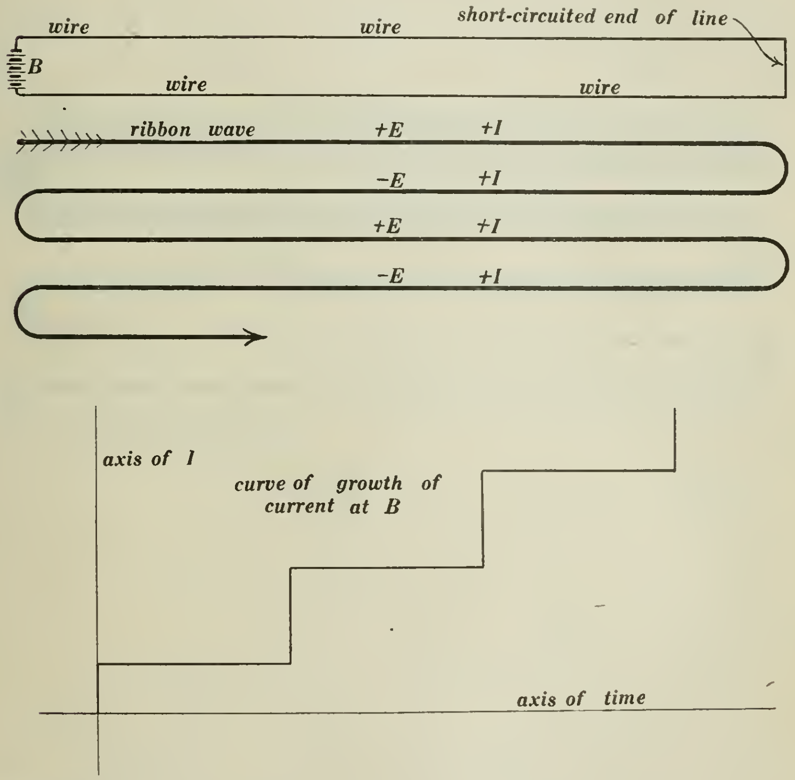


Fig. 34. Same as Figure 33, except that Distant End is Short-circuited.

laps and a fraction of the next lap. By adding a number of laps in this way, curves can be plotted showing the actual distribution of voltage and current over the line at any given instant; or values of current and voltage at a given point of the line can be found for successive instants and from this data curves can be plotted showing voltage or current at any point as functions of elapsed times. The ampere-time curves in the lower parts of Figs. 33 and 34 were obtained in this way.

NOTE.—The character of the reflection at B in Figs. 33, 34 and 35 is determined by the condition that the sum of the voltages in the successive laps must always be equal to battery voltage E, and

of course there is always an odd number of laps at B, one, or three, or five, etc.

NOTE.—Figures 33, 34 and 35 show what takes place when a direct-current generator or battery is switched on to the line, *but on*

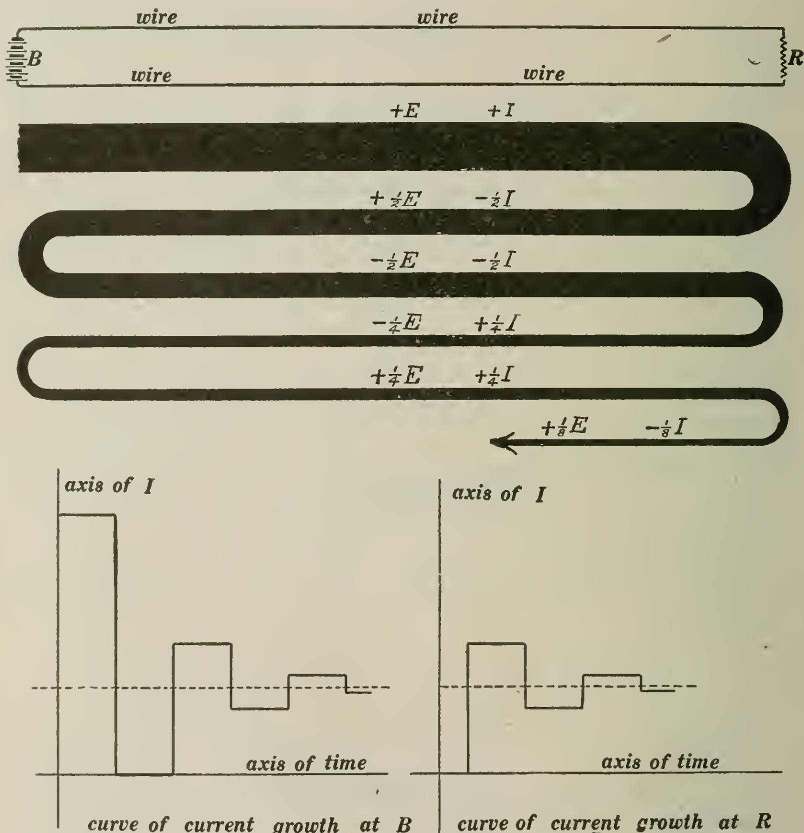


Fig. 35. Same as Figure 33, except that distant end of the line is connected to a non-inductive circuit of which the resistance is $R=3\sqrt{\frac{L}{C}}$. In this case the ribbon wave is only *partially* reflected from the end R and the successive laps of the ribbon wave are thereby greatly reduced in intensity as represented by the shading.

a line of moderate length a number of laps are formed in an excessively short interval of time, and therefore Figs. 33, 34 and 35 show quite accurately what takes place immediately after an alternator is switched on to the line, E being the value of the voltage of the alternator at the instant of closing the switch.

TRANSMISSION LINE SURGES WHICH ARE PRODUCED WHEN A CIRCUIT BREAKER OPENS.

When a circuit breaker opens, the arc which is formed persists for a very long time, relatively speaking, and the open gap in the circuit is filled with a fairly good conducting material which slowly loses its conductivity. It is about as nearly impossible to produce characteristic line surges by opening a circuit breaker as it would be to set up an abrupt water wave in a canal by allowing a cubic mile of soft mud to flow into the canal prism to stop a troublesome flow of water in the canal; and yet the moon, as a 60 cycle generator, (60 cycles per month!), might produce a troublesome tidal wash in a large estuary while the attempt was being made to "open-circuit" the estuary in this Brobdignagian fashion! Let the reader consider this hydraulic analog carefully. It reproduces nearly all

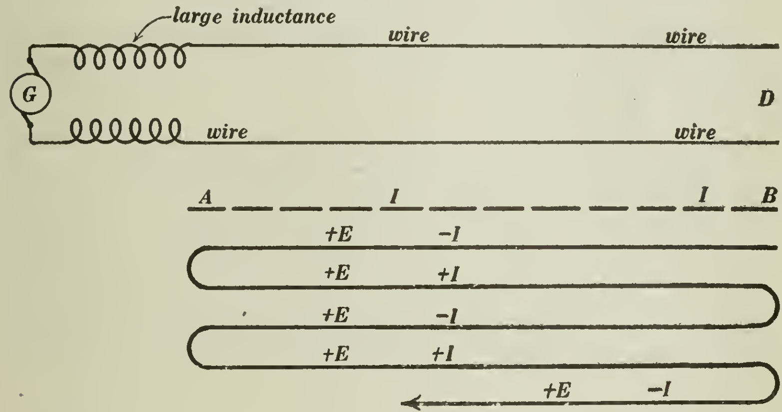


Fig. 36. The dotted line *AB* symbolizes the initial current in the transmission line. The long heavy arrow with laps represents the ribbon wave which comes from *D* after the line at *D* is opened.

of the essentials of the electrical case. The conducting vapor in the arc of a circuit breaker is somewhat analogous to mud as a dam building material.

Very little need be said of characteristic line surges in connection with opening of switches, except in case of very long lines. When a line is short, or only moderately long, what takes place may be described quite accurately in terms of the simple ideas of the elementary alternating-current theory, where current values are supposed to rise and fall simultaneously throughout an entire circuit. The formation of a long arc between line wires in air and the quick snapping out of such an arc does, however, produce an electric wave disturbance on a transmission line of moderate length, and the essential features of this case are shown in Fig. 36. Imagine the system to be short-circuited by an arc at the distant end *D* of the transmission line, voltage being reduced to a negligibly small value

over the whole line, and a large current I being established in the line. The generator is to be thought of as having a large inductance so that the generator current cannot change perceptibly during the very short time required for the characteristic line surges. When the distant end of the line is opened, a ribbon wave shoots towards the generator, is completely reflected at the generator with reversal of current, again completely reflected at the opened end D of the line with reversal of current, and so on. The first lap of this ribbon wave wipes out the current in the line and lays down a certain voltage E $\left(= \sqrt{\frac{L}{C}}\right.$ times the initial value of the current).

The second lap of the ribbon wave lays down a double voltage, and the original current. The third lap wipes out the current again, and lays down a voltage equal to $3E$, and so on.

NOTE.—The character of the reflection at the generator in Fig. 36 is determined by the condition that the sum of the currents in the successive laps at A must always be equal to the initial current I because the current in the highly inductive generator does not have time to change perceptibly.

NOTE.—It must not be imagined that the sending out of a ribbon wave depends upon a continued supply of energy at the point where the ribbon wave originates. Thus, in Fig. 36 the ribbon wave is superposed upon the initial current I, and the first lap of the ribbon wave wipes out this current. Therefore since the current is zero, there is no energy flow at all from the opened end. The second lap of the ribbon wave lays down the original current I and a doubled voltage $2E$, and this combination of voltage and current represents a flow of energy from the generator into the line.

REFUSE DISPOSAL

By Rudolph Hering,* *M. W. S. E.*

Presented June 11, 1917.

Mr. President and Gentlemen of the Western Society:

It is with very unusual feelings that I am here tonight. Besides giving you a little talk, it is like coming back to an old home. I do not think that I have attended a meeting of the Western Society for thirty years. It is almost an average lifetime.

In 1886 I was honored by an invitation from the mayor of this city to come here and help out on a very difficult problem. It was the problem of Chicago's sewage disposal. She was then putting her sewage into the same pot, he told me, out of which they took their drinking water, and they did not like it. He wanted an engineer who had had experience in both water supply and sewage disposal, and at that time such men were scarce, as the settlement of those questions was still in its infancy. A few years before this I had been sent to Europe by the U. S. Government to make a study of the sewerage systems of Europe, and shortly after in my home town, Philadelphia, I was engaged to work out a new system of water supply. So there the mayor's condition was fulfilled. I was very ably assisted by a number of Chicago's young engineers, of whom some are still with us, and we studied the question thoroughly from all sides.

The custom was, at that time, to look ahead about thirty years; not much longer, because the conditions changed so much by then. That time has now passed. It has been one of the satisfactions of my life, not only to live long enough, but to see that our recommendation of 1887 really was the right thing for the city to do. Although not enjoying, as yet, a perfect solution, as might be possible under ideal conditions, you have had vastly better results than if you had adopted any one of the other plans proposed at that time. I congratulate Chicago on the success of that Drainage Canal, which has done a great deal, I think, to help the city's progress and comfort, and to enlighten the profession on the question of disposing of sewage by dilution, which was at that time violently opposed by many people. Today the question of disposing of sewage by dilution, up to its proper limit, is accepted all over the world and practiced in Europe as well as here. Chicago was one of the first cities to demonstrate the efficiency of this method on a large scale.

Excuse my saying all this about a subject on which I was not asked to speak, but I could not help feeling at home here and my thoughts went back to that interesting year when I helped you solve this great question.

I was asked to speak to you tonight about something quite dif-

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ferent;—Refuse Disposal. It is not the disposal of the liquid refuse, which was our problem thirty years ago, but the disposal of the solid refuse of the city.

After I left Chicago in 1888 I attended a meeting of the American Public Health Association and heard a report by physicians on refuse disposal. I asked several engineering questions which had not been thought of by them, and was punished for the intrusion by being put on the committee. At that time refuse disposal was hardly considered worthy of a serious thought and everybody had his own opinion about it. So I suggested that we send out a carefully compiled circular of questions to every city in the United States and ask them how they collected and what they did with their refuse. There were one hundred and forty-eight questions and we got answers to a very few of them. We made a second effort and got some more answers. The third time they were sent out, with a special request to answer only those questions that were easy to answer, but please to do this. Well, we got enough information then from over the whole United States to have a very good idea of what this subject of refuse disposal really was and meant.

In the meantime I had gone to Europe several times looking after questions of water supply and sewerage and incidently examined garbage plants in every city I visited. After five years of study we made a report with certain general conclusions and recommendations. They did not suit all the advocates of one or another method of disposal, but they suited us, and that report still represents the general views held today.

Now, what do the materials that constitute this city refuse consist of? What are they? Refuse consists of garbage, which is the refuse food material thrown away from kitchens and hotels, left over in the preparation of food, and from slaughter houses, markets, and so on.

Then it consists of ashes, i. e., whatever is left from burning coal in the kitchen range or furnace.

Then it includes manure and street sweepings.

Another class of refuse we call rubbish. Whatever is not garbage, ashes, manure or street sweepings, we call rubbish. This includes wood, discarded clothes and bedding, leather, boots, glass, broken jugs and so on.

Dead animals also constitute a part of the city refuse, but dead animals are usually kept separate from the rest, because every city has a private party that collects the larger dead animals and utilizes them for profit and thus relieves the city of that burden. Small dead animals, such as rats, mice, cats, perhaps small dogs, go in with the garbage.

Of course, all this refuse has existed since communities began and we find the first references to it in the Bible. Then the Hindus, Greeks and Romans had their troubles with this refuse, and also the Christians of the Middle Ages. The usual way of dealing with

this rejected stuff was to bury some, burn some, and dump the rest. That the ancients did and to a large extent we do this today, and to some extent will continue to do, so long as it is entirely sanitary.

About 1860 London, being the largest city in the world, began to have trouble with the refuse, rubbish and garbage. The hauls began to be so long that this became very expensive. The same trouble appeared elsewhere in England and this was the first country to really take hold of this refuse question and study it thoroughly.

It was not until 1874, though, when Fryor, in Nottingham, constructed a special furnace for burning all this matter, much of which was formerly dumped or buried. This started the system of refuse incineration. It was crude, but it did the work. It caused an odor, offensive sometimes, because they did not know at that time just how to prevent it, but it was a start. Since then a series of improvements have been made and are continuing to the present time.

In our country, Lieutenant Ryder was the first one to build one of these refuse destructors or incinerators. It was located on Governor's Island, New York, at the military fort.

At about the same time somebody in Vienna had suggested that as there was a lot of grease in garbage it should be separated and utilized. Of course, all the rest of the refuse had to be dealt with in some other way.

I do not know where the first plant of that sort was erected in the United States, but there are a number here now which we call reduction plants. Some have been successful because profitable, although not in every place. Generally they spread a very offensive odor.

About 1896 R. H. Thompson, city engineer of Seattle, went to Europe to study the matter, reported in favor of incineration for Seattle and erected one of our first good furnaces there. In 1896 Colonel Waring made an investigation for New York and recommended certain conclusions. Another report was made for New York in 1904, in which still further recommendations were made, based on extensive experiments and examinations. Then Boston and Buffalo made reports. In Westmount, which is a suburb of Montreal, Canada, an incinerator was erected after sufficient study, which is the first modern, good incinerator, this side of the Atlantic, still in operation, doing its work, without offense and at a reasonable cost; it utilizes its products and is successful. Then we have had investigations made in Rochester, West Brighton, Milwaukee, San Francisco and also in Chicago a few years ago.

In order to judge this subject properly it must be considered from three points of view. In the first place, we must endeavor to prevent the dissemination of disease, then we must prevent a nuisance, and thirdly, we must do both at a minimum of cost. Those are the three problems that the engineer has to solve.

Fresh garbage does not carry disease germs. We do not bring anything into our kitchens that is not healthy, and what we throw

away is not unhealthy. But later, after the garbage has been standing in the pail, flies get on it and breed. The fly is a disease carrier, because, while it does not carry any disease from the garbage, it goes elsewhere, into privies, and where there are disease germs. It picks them up and flies into the kitchen, wipes its feet off on the bread and other foods. We do not know where the fly has been, but we do know that a great deal of disease has been transmitted in this way by flies. The only way garbage is responsible for disease is when it stays uncollected for a long time and is a fly breeder. As the garbage should be frequently collected, it should not be responsible for fly breeding.

Ashes are not disease breeders, and there are no disease germs in ashes.

Then we come to rubbish. That is a dangerous class of refuse, because it includes discarded bedding from sick rooms, sweepings from rooms where sick people have been, and discarded clothing from sick people. Rubbish is really, as I think, one of the most dangerous parts of the city refuse, so far as disease carrying is concerned.

Manure is objectionable as a possible disease producer, because it may carry disease germs directly, more particularly in night soil coming from human beings. Manure also acts as a fly breeder, and the flies again do their part in carrying disease germs.

Finally, street sweepings. When the air is very quiet the bacteria contained in it will settle down and fall on the surface of the street. Analysis has shown that the street dust retains a vast number of bacteria. Some of them are undoubtedly disease producing. For that reason the "spitting ordinances" have been introduced very broadly to prevent tuberculosis germs getting on to the sidewalks, from where the wind raises them up so that we breathe them.

That is the aspect concerning the prevention of disease.

Now, the nuisance question. Among the different classes of refuse garbage is the greatest offender in this respect. Being dead organic matter, it is very soon attacked by bacteria of putrefaction, and putrefaction causes an offensive odor. In order to prevent this we must see that the garbage is rapidly removed before bacteria can putrefy the organic matter.

Manure comes next and we should dispose of it fairly rapidly to prevent offense.

Ashes are not offensive. They do not even make a nuisance excepting through the dust which, when raised by a wind, is objectionable in the neighborhood.

Street sweepings are like ashes in this respect. A wind storm, if the streets are not kept clean, lifts the dust into the air and causes a nuisance. Our modern system of cleaning streets by flushing is an excellent means of preventing such dust. In those European cities where they practice flushing there is no dust. Flushing is now used in New York, and I think partly here in

Chicago and other cities. We are progressing in that line very nicely. Dust is a nuisance.

The engineer must design his works for disposing of all these various classes of refuse in a way which will prevent disease germs from getting to us and prevent a nuisance. Various ways, of course, are used to accomplish this. We can do it today without any trouble. It only needs proper design, proper construction, proper operation, and always proper attention. The decision as to which of these various practicable and successful methods of disposal is to be recommended to a city depends upon the cost, to ascertain which is one of the engineer's chief functions.

I shall discuss the subject under four general heads, namely: the house treatment of refuse, its collection from the house and delivery to the place of disposal, the kind of disposal we should have, and then finally, the detailed cost of what is to be recommended.

There are two ways in which we may accomplish refuse removal. One is by mixing everything, by putting all into one can and having one disposal and one operation. Everything that you no longer want, garbage, ashes, rubbish, manure and so forth, is put on the same pile and taken away together and disposed of together. This is done today almost everywhere in England, and in most of the cities of the continent. In our country the custom is often different, due to the fact that you can get a lot of grease out of the garbage. We, therefore, separate the garbage from everything else, and take it to some works where the grease is taken out and profitably sold. This means that all the rest of the refuse must be disposed of in some other way. Some people have believed it to be a great deal cheaper to dispose of garbage by this reduction method, than to incinerate all of the refuse; forgetting that they were only dealing with one part of the city's refuse. Ashes and rubbish could often be dumped in some low lot without objection. In this way the reduction system got a foothold in our country and spread into almost every large city. No doubt the grease is valuable. I found that in New York a lot of it is being shipped to England for soap making. It is good because of the combination of animal and vegetable grease and has a high value.

We, therefore, have in our country, two general methods. One is the separation of the refuse material into two or more classes, and the other is the practice of combining everything and disposing of it together. We have a somewhat more complex problem than they have in Europe. The reason for this is really that we are very wasteful and throw away much grease with our food waste. When European engineers come over here and see how we waste our water, our electricity, and our food, they are astonished. We use at least twice as much water per capita here as they do in Europe, even in London, Paris and Berlin. We produce about twice the amount of garbage per head in this country than they do in Europe, and we throw away twice as much grease. There was only one place where they tried the separate, or, as they called it, the Amer-

ican system, and that was a city near Berlin, Charlottenberg. They abandoned it after five years, because it was not profitable. Why? Because there was not enough grease in the garbage to pay for its extraction. It is generally a question of cost and, therefore, an engineering, not a medical question, to determine how to dispose of these different things in the most economical way. It is not an easy subject, because it requires very careful consideration and balancing. Cities ought to appreciate this difficulty and appropriate the necessary money for investigations. They are now doing it more than they used to.

Now let us take up the house treatment. The house treatment is very important and it was not considered so until recently, until it was found that it makes a great deal of difference as to where the people put their garbage, into what kind of receptacle, how it can be collected; in short, how it is to be treated at the house, the location of the cans, the frequency of collection, etc. In the future these details will all be studied, and must be studied by the engineers so as to get the best solution for the least money.

In several cities—in Minneapolis, where it started—they recommended the house treatment of the garbage, to be done in this way: It had to be wrapped in paper and then either tied up for collection or put into a receptacle; but it had to be wrapped in paper so as to keep it away from the flies and made less attractive for the dogs and cats. It worked very well there, so the City of Trenton, N. J., adopted the same system, and also found it very successful. I do not know whether it has been used anywhere else.

The collection from the house to the place of disposal is next, a larger subject than usually presumed. It has been very ably treated by Mr. Greeley, of Chicago, in a paper he read before this Society. It has formerly hardly ever been considered from an engineering point of view, and yet very much depends on it. In fact, it is usually the most expensive part of the whole refuse disposal question. It costs more to take the garbage from the house to the place of disposal than to dispose of it, and often should decide the method of disposal. A very long haul may cause the selection of a different method of final disposal than if you had a short haul. It also contributes much towards giving the people the best service. The people want a clean, and orderly service, and if it can be had for a reasonable price, the city has no trouble in enforcing whatever rules may be necessary for the purpose.

A good deal could be said about the cars, wagons and other equipment of the service to collect city refuse. We may have all sorts of cans, and it is an engineering matter to determine what are the best sizes and shapes and how they should be constructed. We now make the cans almost always of metal, of a proper shape and size suitable for the special service in the locality where used. We may have large or small wagons. It is found that the larger wagons, particularly in the larger cities where the houses are close together and where they can collect a big load in a short time, are

far cheaper than small wagons for smaller loads. All these questions, as you can readily realize, are matters of engineering and should be examined and carefully considered and estimated.

In most cities collections are made by horses. We now have in Europe as well as here a movement to use motor cars. The question must be answered, under what conditions is horse collection cheaper, and under what conditions is the motor truck cheaper. The collection by horses is now cheaper if the collections are frequent. When you consider the collection for combined or mixed disposal, you have entirely different conditions from those which exist if you have to collect the garbage alone. Garbage should be collected every day in hot weather in a big city, certainly not less often than two or three times a week, and other materials separately; ashes, perhaps, only once a month. You see the collection may be somewhat complicated, and requires an engineer's work to find the right solution.

In large cities where the haul is very great there is another study necessary. We find it cheaper to have transfer stations within a large city where the refuse can be delivered from the houses, and then dumped either into cars, trolleys, big motor cars or railroad cars, to be taken quite a distance than when hauled without transfer by a single cart or a motor. Therefore, large cities are now installing such stations and having supplemental transportation to the point of disposal.

Finally we shall consider methods of disposal. In our country, where we are so extravagant, a great deal of stuff is thrown away that still has some value and money can be gained by picking over and sorting the discarded refuse of a city. I saw them do it in London at a station on the Surrey side, right in the middle of the metropolis, at one of their incinerators. Everything was dumped on a moving belt. There were about thirty girls at work; some were picking out paper, some rags, some bottles. Each article was put into a large barrel and then sold. There was a little profit in it, but it was an unhealthy and very disagreeable occupation. I asked some of these girls whether they did not dislike this sort of work, and they said no, it was not any worse than a lot of other dirty work they might have to do, and they had eight working hours, after which they were entirely free and could do anything they pleased. Servants are engaged for practically the twenty-four hours, and in the stores women work about ten hours. Here they had three eight-hour shifts. The Boards of Health do not like this occupation, and I think the tendency in Europe is to stop this picking everywhere. Picking is worth more here because we throw away more valuable things.

The Buffalo records show a profit, after paying all expenses, interest and depreciation, but it is very small, about two thousand dollars. It seems to me that we shall gradually come to think, as in Europe, that it is better to give up this little profit than to put

up with all the disagreeable and dangerous features of the sorting plan.

There are various methods of final disposal for this refuse. There is the land dumping, which is the oldest method. We have been dumping from time immemorial, and we shall continue to do so where it is safe and economical, only we should do it better than it is ordinarily done. Dumps can be made entirely healthful. They can be properly arranged and regulated, with a man on the ground to indicate where the next load should be dumped. If we know what sort of material is coming we can have the loads with inoffensive material thrown over what is offensive, or we can borrow earth somewhere and spread it over the dump. There are many ways in which you can make the dump for much of a city's refuse acceptable, perhaps not right in the city, but near it. Materials like ashes can always be dumped, and rubbish probably also, provided it is covered. Paper particularly should be covered, because it can be blown about, which is disagreeable, or somebody may start a fire and that makes a bad smell. We see a good many of our rubbish dumps set on fire because it is thought an easy way to get rid of the material, but this way of burning is quite offensive.

Garbage has sometimes been dumped without objection when it is mixed with other refuse, but when raw it should never be dumped, because it will rot and cause trouble unless it is covered with earth within a short time.

Now, there is another way of dumping. Garbage may be dumped into running water, into a river or the ocean. New York disposed of its garbage for many years that way. It had big scows, boats loaded with this garbage, and took them out to sea and dumped them. They found that the waves and winds would bring some of the garbage back to the Jersey shore, which you know is used extensively for bathing purposes.

New Orleans has dumped its garbage into the Mississippi River. I think it is one of the best disposals because it is dumped in the middle of the river below the surface. Some of it may rise to the surface and float, but it floats in one direction and gets into the Gulf of Mexico. Hardly anyone lives on the banks below the city. There are cases where such dumping can be done, but those cases are very rare.

I do not think dumping into a bay is safer or always feasible. Both in summer and winter such dumping might give trouble.

Another way to dispose of garbage is feeding it to pigs. That is a very good method, a cheap method because it returns more money value than any other way of disposal. In New England it is very common to collect garbage from houses by the separate system and take it to farms and piggeries and there dispose of it satisfactorily with a good profit. These feeding places may, however, be very disagreeable unless they are properly designed and managed. You should have a concrete platform upon which the pigs can stand, and properly constructed troughs that can be cleansed

and washed out. These should be provided with plenty of water so that every part can be kept clean. The garbage, when delivered, must be fresh, and should be fed within twenty-four hours after collection. It is a perfectly proper and economical method of disposal, and I do not think we shall ever give it up, where it is at all feasible. It is not feasible for large communities, because it is not economical to deliver the material quickly enough. Hotel garbage, however, is generally very good for pig feeding and usually can be economically handled.

Another common system of garbage and rubbish disposal is by shallow burial. That method of garbage disposal is very important because it is used in many cities, including Berlin, with a population of two and a half millions. Channels are plowed into the soil about 18 inches deep, the garbage and refuse is thrown in, and the soil filled over it. In the course of two or three years all putrescible organic matter is decomposed. We have had some experience with this method in Milwaukee. I examined the material myself after it had been buried one year, two years and three years. After three years you could find some tin cans, iron wire and resistant organic matter, like bones, that would not decompose, but all the offensive organic matter was gone. That is a very cheap method. It is particularly successful in Berlin, because the soil is quite sandy. It has made that land much more fertile than it was before. I think burial is one of our best systems, particularly for small cities.

We have yet to consider two more methods usually employed in large cities. One is the reduction method, of which I have already spoken. It is used in most of our large cities, and you use it here in Chicago. We use it in New York, Philadelphia, Baltimore, Washington, and many other American cities. Various processes have been tried. The first one was a cooking of the garbage with steam, followed by the application of naphtha, which dissolved the grease and separated it from the garbage; the remainder is called tankage, a material that can be used as a fertilizer filler. The difficulty with this process has been that the offense was great and therefore that it was a niusance. We therefore built the works away out of the city. That meant a long haul and expense to the city. In Milwaukee a study was made between this reduction method with a haul far out of the city and the incinerator method with short haul right in the city. It was found that the short haul made the latter system the cheaper one, although, had the hauls been alike, the former system would have been cheaper.

The best system we have today appears to the Cobwell system, which is operated in Los Angeles, and will be used in New York City. I say it appears to be the best because of all the reduction plants I have seen, this one is operated with the least offense, due to the prevention of offensive odors.

The chief profit derived from operating a reduction works is from the sale of grease, which has a market value of from 3 to 5 cents a pound and is used chiefly for soap and candle making.

The other system, the last one I shall mention for disposing of refuse, is incineration. That is the common system in Europe, and it is practiced here also. It can be made entirely sanitary. Disease germs will never go through a fire, and if the temperature is high enough there never will be a nuisance, provided we keep the works clean, which is not difficult. It costs a little more money, but that money is well spent. Some incinerators are being surrounded with parks, with trees and flowers. I have found plenty of incinerators in Europe in the densest parts of the cities. We could have them here. I see no reason why there should be any objection, if we build and operate such works as we know how to do.

Ashes containing unburned coal assist very much in the incineration of refuse. In our country, as well as in England, it has been found that sometimes twenty-five per cent of the ashes is unburned coal. That is the reason why incineration in this country and in England has proved successful. We can get a very high heat. The heat necessary for incinerators is at least 1,250 degrees and this temperature destroys all organic matter, and you are sure you will not have odors. It is usual to have an average temperature of 1,000 or 1,500 degrees. Sometimes there is carelessness in operation; that is, in feeding and stoking, which reduces the heat, and then unburned gases go out of the chimney and give an odor. That is one reason why some of the incinerators have been found objectionable. But there are no inherent difficulties. Trained firemen can operate properly constructed incinerators without producing offensiveness.

There have been many designs for incinerators since Fryor's. We have front-feeding, back-feeding and top-feeding furnaces. We have had hand feeding and mechanical feeding, where the garbage is brought to the furnace and dumped into a hopper and discharged upon the grates. We have also furnaces where the clinker is taken out by machinery, as in Savannah, Atlanta, San Francisco, Toronto and other cities.

We find quite a number of mechanically operated furnaces in Europe and America. It pays to have mechanical equipment in large cities, because it is cheaper and cleaner. Of course, it also requires greater intelligence. All the best disposal systems, particularly in large cities, require intelligent supervision and intelligent labor. In fact, we want more intelligent labor in most of our modern improvements.

City refuse is the most heterogeneous mass of matter on this earth. It contains solids, liquids and gases of great diversity, metals, stones and organic matter in every possible condition of rottenness. This complexity makes it difficult to deal with. If you put it all together there is no better means of destroying its objectionable qualities than with fire. It converts the whole mass into two materials. One is steam and the other is clinker. Steam is valuable and has been utilized in several places for different purposes. In Europe it is used for making electricity to light the towns; in

Hamburg for charging storage batteries and collecting the refuse with trucks, so that the collection of a certain district does not cost anything for power. In Westmount, Canada, they light the entire town by electricity made from the combustion of the town's refuse. In Milwaukee they have converted the steam into electricity and used it on the pumps which flush the river; in England for pumping either water or sewage in a number of cities. I think there is quite a future in a further development in this direction, so as to get the full value of these products of refuse incineration.

The clinker is generally used profitably in Europe. Here it has mostly been disposed of for filling. In Seattle it was ground up, mixed with cement and made into building blocks. The new incinerator in Seattle is built from the clinker made at the works. In Europe they make flagstones for paving, blocks for street paving and all sorts of ornamental figures.

Recently a proposition has been brought to our attention for extracting alcohol from garbage. It remains to be seen how profitable it will be. It may be profitable, but only an experiment on a large scale will finally decide it.

The practice of refuse disposal is developing, it seems, along the lines I have spoken of this evening. But there is a good deal yet to be learned, and a good deal of skill to be applied in perfecting methods, apparatus and operation to serve our communities with in this respect.

Mr. Hering then showed and explained a number of slides taken in the United States and Europe and covering the various phases of the subject.

DISCUSSION.

Colonel Henry A. Allen: A statement should be made in regard to the nomenclature. We use the terms "garbage," "rubbish" and "ashes," all coming under the general term "refuse." Our connections are made on that basis—ashes, rubbish and garbage.

We have found that it does not pay to incinerate ashes because of so large an amount and, therefore, as fast as we can institute separation of ashes, we use them for fills. The question now is to build and construct loading stations that will readily handle ashes. We know how to do this. New York and Brooklyn have very good loading stations for ashes, and with improvements Chicago can load ashes into cars without any inconvenience even to next door neighbors.

Now, in regard to the questions of waste disposal. At the time Mr. Hering refers to, the construction of the Sanitary District Canal, except as a temporary measure, I have been opposed to the dilution method of the present day disposing of sewage. With the present improved system of screening, certainly the larger portion of solid sewage matter can be separated and disposed of in several feasible different ways.

It does not always pay to treat the effluent. This matter must

be given attention, but certainly we should begin by taking out the solids, not only because of difficulties from clogging and filling our waterways, but because of the serious menace to health. In addition such screening prevents unsightliness and odors along banks and shores of rivers and lakes, hence enabling maximum use for the enjoyment of communities. Sewage should, at least, go through screens and where it is a question of preventing pollution, it should be put through disposal stations or works and the effluent discharged into the streams in a sanitary, clear and odorless condition.

One thing the City of Chicago has done, which can be pointed to with pride and we must give the women of Chicago credit for having put the thing over and made it a real business—the appropriation of considerable sums of money for use in experimentation. We have made many experiment, a great many more than have been spoken of, in handling equipments, disposal equipments and other equipments relating to Garbage.

It is a fact, as Mr. Hering has said, that the most difficult part of the problem is getting the garbage from the householder into the collecting wagon. The question of the collecting wagon itself and transporting it from there to the disposal works are comparatively simple matters, just plain questions of engineering, keeping in mind unit costs. The question of getting the garbage from the householders to the wagons, however, is a difficult engineering problem. It is the more so as cities are not laid out so that uniform collection apparatus can be used in all sections. Sometimes we have paved streets, sometimes not paved. Sometimes we have alleys, sometimes no alleys. Therefore, up to the present it has ben impossible to design a universal, up-to-date garbage box.

In the selection of a garbage can its adaptability to be readily loaded on to collecting wagon, or its contents dumped therein, must be given consideration. The size of the collecting box is most important, as, other things being equal, the larger the capacity and the more readily loaded, the greater the efficiency of the entire collecting system. Various types of wagons have been gotten up, several arranged to work in conjunction with the garbage can, so that the garbage is kept entirely from sight during the receiving of garbage from can and in transportation. Just how far this principle is carried depends greatly upon the time during the day that the collection of garbage is made and also on the number of collections made per week. When collections are made three or four times a week very little offense will result, whereas if less often and in hot weather the garbage will emit very offensive odors.

We tried in Chicago to use a 6-cubic yard box, the reason being that our present garbage box holds about four cubic yards, and rubbish wagons five cubic yards. A 6-cubic yard box would mean a 50 per cent increase in capacity for each single load in the case of garbage and 20 per cent increase in the case of rubbish. But when taking into consideration that only 18 per cent of the alleys are paved about 60 per cent of the streets, we decided that a 4½-cubic

yard box would be the best all-around and convenient size. The larger box would require the use of 3-horse teams in many parts of the city. It would be rather difficult to handle 3-horse teams in many of our narrow alleys. The idea was to design a standard collecting unit that would not only handle garbage, rubbish and ashes, but also night soil, street sweepings, sewer cleanings, manure and material of a similar nature. The result would be the standardization of equipment, such as wagons, motor trucks, barges and handling equipment.

The Chicago River and the Sanitary District Canal are well located for convenient handling of a large portion of the various municipal wastes. The city has one loading station at Chicago Avenue, that it is expected soon to move to Goose Island, where it is proposed to erect a large loading station for the handling of garbage, rubbish, ashes and manure. We are endeavoring to make this an up-to-date loading station. Another loading station is situated on the North Branch of the Chicago River on Oakley Avenue near Diversey Street. It is the intention to erect two additional loading stations on the Chicago River or the north branch of the Sanitary District Canal to take advantage of water transportation. It is possible that two other stations may be situated on the Sanitary District Canal near 14th Street and California Avenue. These stations will also be convenient for barge service.

In a paper I read before the American Society of Mechanical Engineers, I made the statement that I considered the following to be an axiom, referring to the handling of offensive substances, namely; that that system of handling offensive substances which exposes the least amount of surface to contact with such substances will be the least offensive, the most sanitary and in the greater number of cases practically the least costly in operation. This idea would mean the keeping of the garbage in the collecting box until final disposition; not dumping it in bins and then re-handling it. In other words, to unload the boxes on reaching the reduction plant but not to dump from the boxes until ready to run it directly through the reduction apparatus. This means an additional number of boxes but the production of less offense at the plant and the saving of a considerable amount of labor. Garbage dumped into pits is very difficult to handle because of matting. In fact, it seems to violate all reasonable rules of mechanics relating to the flow of materials.

At present the time our reduction plant is not as it should be, but you must remember that really we had a very difficult fight, as Miss McDowell knows, to get control of this plant. After obtaining possession I had only about three months to put the plant in shape. For that reason the design of the large bin, which occupies the floor space where formerly in the summer time the garbage was piled up in the open, sometimes as much as 500 tons of garbage being exposed to view and smell. This large bin will hold about 1,400 tons of garbage and will keep it entirely from

view. It is safe to say we have practically had no offense since this part of the plant has been in operation.

Now comes the question of the various systems. The drier system will give 50 per cent more grease approximately, at least 40 per cent more, and that is quite an item. Experiments made with what we call petticoat stacks at the plant and low temperature drying, which I have worked out for the city, have resulted in practically no offense from our dryers. The petticoat stacks act not only in air dilution, but to lower the temperature considerably, causing a deposition of moisture. As the moisture precipitates it carries with it a certain amount of solid matter which when collected is worth about fifteen dollars a ton. This solid matter often contains odors and is disagreeable, and when not thrown down naturally is carried off with the air and other gases and becomes a nuisance.

We expect to have the new system in operation in about sixty days. It has been delayed, like all work of late, because of difficulty in obtaining material, such as fire brick and the like; but in about sixty days we will have the new drier house, which we can call an up-to-date drier house, in operation.

Incinerators or reduction plants can be designed with equal ease to operate in a sanitary and inoffensive manner. In most cases engineers have tried to design cheap, I say cheap and not well, and the examination of a large number of plants will show that. This is often due to the fault of the engineer in not asking for the amount of money needed to go through with it right. The public does not care to have you design cheap. The people want you to design well and they are willing to pay the price, provided they have confidence in the engineer that the designs are right, and that the money for the designs will be properly disbursed.

You will find in Chicago, where a great deal of money has been spent on its reduction plant, that such was brought about by conditions of service. We had an old plant which had to be gotten rid of. If the plant were moved, it was feared it might be to some other alderman's ward, causing him trouble. So the aldermen said, "Let us keep it where it is because they are used to it there." We could have built a new plant of fifteen hundred tons capacity for a million and a half dollars; while this will probably cost a million more, because of so much temporary work. It is not exactly a pleasant feeling to have structural steel work going on next to big gasoline tanks, especially when you know people are not very friendly to you.

Coming down to the latest advance, I might mention that Dr. Hirsch early in the game proposed making alcohol from garbage. Perhaps earlier than that, several patents have been taken out on the treatment of garbage and the manufacture of alcohol. After some experimental work, I was convinced that it could be done, but could not get the inventors to make suitable demonstrations so that I could report to the Mayor and the City Council that

such processes were feasible. It can be done. I cannot do it because I am not enough of a chemist. Dr. Morgan asked for assistance in this line and experiments were made at the plant which resulted in our getting quite a little knowledge, though the results were not sufficient to warrant carrying the experiments further for the city. Dr. Morgan then took up the question with the City of Columbus, Ohio. Possibly some of you may have read the report of the results, made by the officials of the City of Columbus on the obtaining alcohol directly from garbage, the starches and other similar matter being converted into alcohol. The method is, in my opinion, entirely feasible. A new phase has been added recently. It is reported that the Germans have been able to ferment garbage and carry the process (naturally a complicated one) a step further, getting glycerine directly. So far we have gotten only the alcohol. It looks as though in a year from now we shall be in serious need of glycerine. If this war continues long, our Government will not allow garbage to be incinerated, thus burning up the greases from which glycerine can be obtained. From every hundred pounds of garbage grease produced at our plant is obtained approximately eight to nine pounds of glycerine, depending upon the season of the year. I am opposed to burning values when you can obtain such values at little or no cost. Our plant at the present time is not a criterion of what can be done, because we have been operating under the most unfavorable conditions. With any ordinary price of five or six cents a pound for grease and with tankage at five dollars a ton, this plant can readily clear a dollar and twenty cents net on each ton of green garbage delivered. This does not take into consideration all the depreciation or the interest on the money invested, but it does take in a large amount of repairs, and our present reports show a very large amount of repairs because we are running an old plant. It is obviously not fair in making comparisons to load this plant with this million dollars extra charge, the cost of municipalizing. Had I been given a new plat of ground, this large extra sum of money would not have been required.

I am fully convinced that we are going to advance very rapidly in the next couple of years in the direction of the chemical treatment of garbage and production of by-products therefrom.

Charles B. Ball: The principal point of view which I have in relation to the disposal of these matters is the nuisance point of view, and we know that it is exceedinbly difficult in a large, spread-out community like ours, to avoid nuisance in storing, handling and disposition of garbage. It is a very large subject, and it seems to me that it might well be left for some other evening to discuss in detail what ought to be done to avoid nuisance. I think it is quite true, ac Colonel Allen has said, that our present plant is practically without nuisance.

John Ericson, M. W. S. E.: In 1913 I visited Europe and took a great deal of interest in reduction and incineration plants, and

methods of disposal. I could not really add anything on what I saw there to what the other gentlemen have said, but Mr. Hering mentioned one thing, and that is, when a foreigner comes to this country he is amazed at the waste of everything, and it might interest you to know that in Stockholm they had a museum in which they placed objects they had collected from the garbage dumps. From what I saw at that museum I should say they were pretty extravagant over in Europe, too. I found, among other things, a lady's saddle, almost new. I found a parlor furniture set. In a glass case on the wall they had pasted one, five and ten crown bills, and a whole lot of things of that kind. It was an extremely interesting museum, the exhibits all having been gathered up from the garbage pile as stated. Another thing there was a map in good preservation, said to be one hundred or one hundred and fifty years old, and considered extremely valuable and rare. This is mentioned to show that they seem to be extravagant over there, too, in some respects.

C. H. Cenfield, M. W. S. E.: One point that Mr. Hering brought out this evening was that this whole proposition was an engineering problem and should be treated as such. In 1913 the Chicago City Council appointed a commission and employed experts to go into this problem, and that commission as the result of their study adopted a plan, which plan has been generally adhered to since that time. Just recently the voters authorized a million dollar bond issue to further carry out those plans. We adopted a policy, as far as disposal is concerned, of reduction and incineration. The plans of collection and transportation, although not worked out in detail as yet are, to me, the biggest problem in this connection, that the city is confronted with at present. The City Council appropriates annually approximately five million dollars for the cleaning of streets, collection of waste and the disposal of the same. To illustrate part of the problem, approximately 70 per cent of the time of teams used in collection of rubbish is spent in traveling to and from the dump and 60 per cent of the time of the garbage teams. Now, our province is to work out a plan, financed by this bond issue, of reducing that cost, thereby rendering better and more economical service for the money expended in operation. The city of New York, according to a statement made in the *Engineering Record*, appears to have made a big start on their collection problem by motorizing certain districts in that city.

W. E. Williams, M. W. S. E.: What success has attended the drying of garbage at the points of origin or nearby, and transporting it farther out for treatment? Has any attempt of that sort been made?

Mr. Hering: The drying of garbage at the house?

Mr. Williams: No, drying it at local stations and then transporting it to other stations for final treatment.

Mr. Hering: I do not know of any such practice. Of course,

garbage evaporates constantly if it is exposed to a dry air, and it is drying all the time slightly.

Mr. Williams: I had in mind a regular drier, such as they dry offal with at the stock yards.

Mr. Hering: No, I do not know of any such thing.

Mr. Williams: Would it be practicable to control the odor in a drier that was drying the garbage near a residential district.

Mr. Hering: There is a drying process in some of the reduction plants. But you do not mean that; you mean at the point of origin?

Mr. Williams: Yes, gather it in local centers near its origin and dry it there and transport the dried product for final disposition.

Mr. Hering: I do not know of any such process. I was going to say with reference to the sewage question which Colonel Allen mentioned, it is not my idea that this solution that we suggested, Mr. Artingstall, Mr. Williams and myself, was intended to be everlasting. It was intended to be about thirty years, or until about the present time. Now, in my opinion, there is a second chapter to this proposition, and it is necessary for Chicago to begin to treat the sewage in this way that will take out the solid matter wherever it is economical to do so. This will relieve the river of an excessive amount of putrefying matter. The solid matter today can be taken out very readily and not expensively by a process which we did not know about thirty years ago, and that, I think, is the intent in the future. Something must be done here to follow up the proposition with an extraction of certain parts of the sewage. It is a new problem today.

The Chairman: We might hear a few words from Dr. J. J. Morgan, who has the question of the extraction of alcohol from garbage particularly at heart.

Dr. Morgan: The knowledge on this subject is sufficient for me to proceed with only the briefest preface.

The operation of the recovery of alcohol from garbage is based upon three fundamental principles:

First. Ethyl alcohol is formed by the fermentation of certain sugars.

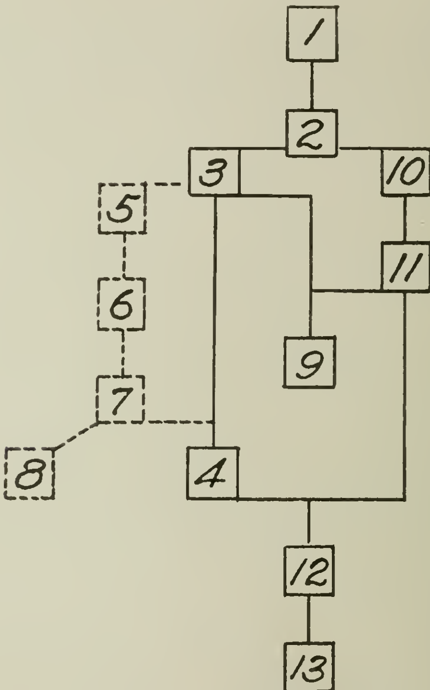
Second. Fermentable sugars are produced by the action of a dilute mineral acid and heat upon starch and certain other similar matter.

Third. Garbage contains starch and certain other similar matter.

It therefore follows that if garbage is heated with a dilute mineral acid and afterward fermented and distilled, alcohol will pass over and may be recovered.

Let me briefly sketch the cooking method of "Garbage Reduction" and point out the ease with which it may be combined with the general principles just given, using the plant at Columbus, Ohio, as a model.

Garbage is first cooked in the Digestor, (1), as indicated in the accompanying diagram, Fig. 1. It then passes through a roller press, (2), where the cooked mass is separated into its solid and liquid constituents; the liquid portion passes into separating tanks,



Outline of Cooking Method of Garbage Reduction

(3), where the grease is removed by skimming and carried into storage, (9); the liquor from these tanks, (3), now free from grease, is carried to evaporators, (4), and evaporated to about 18 degrees Beaumé, where we will leave it for a moment. Returning to the solid matter from the roller press, (2); the solid matter is carried to a direct heat drier, (10), and dried. The dried material is then carried to a percolator, (11), and extracted with gasoline; the grease recovered by this extraction being added to that obtained by skimming. These two constitute the total grease recovery, which is now collected in the Grease Storage, (9). The grease-free tankage from the percolator is now mixed with the evaporated liquor from the evaporators above mentioned and the mixture passed through the drier a second time, (12). The dried mixture is then ground and passes to storage, (13), and constitutes the finished fertilizer tankage.

To combine the alcohol recovery system with this process,

instead of cooking the garbage with plain water we add sufficient commercial sulphuric acid to constitute from 2 to 4 per cent of the weight of the garbage and then cook. The mass then proceeds precisely the same as in the simple cooking process above described down through the separating tanks, (3). From here, however, the liquor is temporarily diverted, and instead of passing directly to the evaporators, (4), follows the dotted lines of the diagram and passes to a neutralizing vat, (5), where the free acids are neutralized with lime. From here to the fermentation vats, (6), where the sugars formed by the action of the sulphuric acid on the starches are fermented to alcohol. From (6) the liquor passes to the still, (7), where the alcohol is distilled off and is collected in (8), while the alcohol-free liquor from the still is now carried to the evaporators, (4). The balance of the operation proceeds in precisely the same manner as in the simple reduction process.

You will see that we simply add a little sulphuric acid at the beginning, temporarily divert the liquor, pick out the alcohol, and then return it to its original course through the reduction process none the worse for its short excursion, since we have only removed the starchy or carbohydrate contents which have no value as fertilizer and which may in fact be considered as a detriment since they dilute the tankage and add useless weight upon which transportation must be paid.

A certain amount of work has been done at the Reduction Plant at Columbus, Ohio, on the application of this process and I will give you a synopsis of a report of this work submitted to the Director of Public Service of that city.

The report begins by stating the conditions calling for the report; this is followed by a brief description of the equipment and the process employed; then follows a table giving the details of 24 experimental runs, using 1,000 pounds of green garbage as an operating unit. This table gives:

The amount of water added.
Length of time steam was applied.
Pressure of steam.
Weight of commercial 60° sulphuric acid used.
Weight of neutralizing material.
Weight of tankage recovered.
Weight of liquor recovered.
Weight of grease skimmed from liquor.
Conditions governing fermentation.
Amount of alcohol recovered per ton basis.

The alcohol recovery per green ton basis (actual still recovery) varied from 2.88 to 7.16 gallons of absolute alcohol and averaged 4.8 gallons of 90% alcohol for the 24 runs.

This is followed by Table 2, giving the estimated cost of additions to the Reduction Plant required for treating all the city's garbage by the Morgan Process.

"The total cost of these additions, according to this table,

amount to $36,000.00." (The original cost of the Garbage Disposal Plant at Columbus was about $235,000.00.)

Then follows TABLE 3, showing the market value of denatured alcohol from 1911 to April 1, 1917.

Then follows TABLE 4, showing the estimated revenue and cost of operation, using present war prices (May First). Alcohol yield taken at 4.8 gallons 180°, per ton of garbage, 20,000 tons of garbage per year.

Revenue.	
4.8 gallons alcohol @ 70c =	$3.36
90,000 gallons alcohol @ 70c =	$67,200.00
Operating Cost	
Total	$40,290.00
Annual Profit	$26,910.00
Return on investment	75%

Then follows TABLE 5, the estimated revenue and cost of operation, based on average prices prevailing during normal times. (Yield and tonnage the same as in TABLE 4.)

Revenue.	
4.80 gallons alcohol @ 35c =	$1.68
90,000 gallons alcohol @ 35c =	$33,600.00
Operating Cost	$29,260.00
Annual Profit	$4,340.00
Return on investment	12%

A few unimportant remarks follow and then the following which is of considerable interest from an economic standpoint:

> If 96,000 gallons of alcohol were produced from our garbage it will result in a large economic saving and conservation of food supplies, such as corn, grain and potatoes respectively, necessary to manufacture 96,000 gallons of alcohol.
>
> 33,600 bushels of shelled corn will yield 96,000 gallons of 90% alcohol or it will require 39,529 bushels of wheat or 110,-344 bushels of potatoes for a similar yield.

Then follows TABLE 6, giving the results of one effort to determine the effect of this process on the grease and tankage; this effort had no practical value, however.

The report ends with the following conclusions:

> (1) Alcohol of satisfactory quality, which should be equivalent in value to the product already on the market, can be produced from garbage.
>
> (2) One ton of green garbage will yield 4.8 gallons of 180° proof alcohol. The reduction works treat not less than 20,000 tons per year, therefore, a yearly yield of 96,000 gallons has been the basis of our report.
>
> (3) A plant of sufficient capacity for treating the entire garbage of the city of Columbus will cost $36,000.00.
>
> (4) Based on present wartime prices the cost of producing alcohol, it is estimated, will be 42c per gallon.

(5) Based on normal prices the cost is estimated to be 30½c per gallon.

(6) A year's supply of our garbages, based on experiments, should produce as much alcohol as 33,600 bushels of shelled corn, 39,529 bushels of wheat or 110,344 bushels of potatoes.

(7) Sufficient experimentation has not been done to determine the exact effect of the Morgan Process on the production of tankage, although with careful manipulation, it is believed that the loss, if any, will not be great.

(8) The quality of grease produced is satisfactory and there is no loss occasioned by this process.

My personal remarks upon this report are in part as follows:

If this report is taken at its exact value, namely, as the report of three men, none of whom were technically familiar with the subject of fermentation, distillation, etc., upon a process practiced with poor facilities and by unskilled persons, it can be accepted as showing the minimum results obtainable under the conditions as stated.

If, however, it is taken as a report of skilled men upon a process operated under perfect conditions, it is entirely misleading and conveys the impression that the results obtained are those to be expected in expert practice. Such is not the case. The facilities for testing the process were very poor, every bit of the apparatus used being home made, with the exception of three fermentation vats, and these were found leaky.

The column still used was home made and after these twenty-four distillations were finished, on a test distillation was found to lose 6 per cent of the alcohol sent through it. How much alcohol was lost in these twenty-four distillations no one can say and there is no allowance made for this loss nor is the fact that loss occurred mentioned in this report.

The fermentations were conducted in a crude manner, many of them in old oil barrels which had previously contained raw garbage, and under these circumstances it was impossible to obtain perfect fermentations.

The gentleman conducting these experiments, Mr. W. D. Bee, Assistant Superintendent of the Disposal Plant, while there is no question of his honesty, faithfulness and desire to do the best work possible under the circumstances (and in fact it is due solely to his honesty, faithfulness and desire to do the best work possible that the results obtained are as satisfactory as are shown), is not a chemist and his entire knowledge of fermentation, distillation, etc., has been gained while doing this experimental work.

It should also be remembered that this report includes everything that passed through the still, fermentations made to test different yeasts, different conditions, etc., and does not represent a fixed established method of procedure.

Finally it must be remembered that in experimental work of

this kind the errors are of necessity errors of loss and that from the conditions there can be no errors of gain.

Under these circumstances, I feel justified in claiming that this report is to be considered as a minimum report only and not a report showing the actual value of the process in expert practice.

It is understood that these remarks are not made in a spirit of unfriendly criticism, but simply that the existing conditions may be fairly understood and the results judged accordingly.

In certain work done by me at the Municipal Reduction Plant of the city of Chicago, an average yield of from 7 to 7½ gallons of alcohol per ton of green garbage was obtained by this process; the average of three analyses made in the Chicago Health Department Laboratories of commercially dried garbage gave 25 per cent of material giving the "Fehling" reaction which was classed as material available for fermentation; one "cooking" and fermentation of this commercially dried garbage gave a yield of 12 per cent or 36 gallons of alcohol per dried ton; as the Chicago garbage at that time carried from 70 per cent to 75 per cent of water these results check fairly well.

This covers the work done to date. Arrangements have just been concluded to have this process installed in a certain plant on a commercially operative scale and, should nothing unforeseen occur, I hope at an early date, to be able to furnish you with detailed information as to its practical value.

BOOK REVIEWS

THE BOOKS REVIEWED ARE TO BE FOUND IN THE LIBRARY OF THE SOCIETY.

LAWS OF PHYSICAL SCIENCE, A Reference Book. By Edwin F. Northup, Ph. D. 210 pps. 5 by 8 inches, bound in flexible red leather. Price, $2.00. Published by J. B. Lippincott Company, Philadelphia.

Considering the immutability of Nature's Laws, it may seem strange to some that engineering formulas and principles cannot be stated in simpler forms. On the other hand, however, the complexity of conditions to be considered, the varying composition of man-made materials, would indicate that progress is being made in many directions.

The laws of Physical Science have not changed since the Creation. Archimedes discovered principles as true today as then. Newton added other principles, and from time to time scientists discover the natural laws governing the action of materials and forces in Mechanics, Hydrostatics, Hydrodynamics, Capillary, Sound, Heat, Physical Chemistry, Electricity, Magnetism, Light, etc.

The author has endeavored to combine in one small volume the general propositions or laws of science, so far as they have been discovered and verified to date. No attempt has been made to state the accepted engineering formulas which depend on these laws, probably because so many of these formulas are empirical, and so subject to limitations. Each law, proposition or general statement is characterized by an appropriate heading or title, and followed by one or more references to easily accessible text-books, standard treatises, original articles or papers, where one may find a more complete exposition of the proposition, or other authentic information on that subject. Some 58 books, journals, etc., are referred to in this manner.

The omission of discussion following each proposition enables the author to condense the book to its handy size, making it particularly valuable for students and others who find portability an asset. C. A. M.

PRACTICAL STRUCTURAL DESIGN, A Text and Reference Work for Engineers, Architects, Builders, Draftsmen and Technical Schools; especially adapted to the Needs of Self-Tutored Men. By Ernest McCullough, C. E., Member American Society Civil Engineers; Consulting Engineer; Licensed Structural Engineer and Licensed Architect, State of Illinois. Author of "Engineering as a Vocation," "Practical Surveying," "Engineering Work in Towns and Cities," etc. 303 pps. 6 by 9 inches. 185 illustrations. Price, $2.50. Published by U. P. C. Book Company, Inc., New York.

In all of his several books the author remembers that the purpose is to instruct, rather than show his knowledge of the subject. As a continuous writer for the technical press, as consulting engineer, as teacher in night schools and private classes, he has found that teaching is an art and that the subject must be so presented as to be understood. A mere statement of fact means little, but an experiment or application verifying that statement fixes the truth firmly.

This book is intended for those who find themselves confronted by problems in structural design in connection with their work. They may be draftsmen, having worked up from office-boy. They may be graduates of grammar school, or the hard school of experience, the more intelligent mechanic taken into the office. Appreciating the need of this knowledge and knowing the difficulty of grasping theoretical problems, the author has tried to keep within the mental limits of these men.

The general nature of the book is a series of articles recently appearing in *Building Age*, to which has been added an equal amount of new material, and the whole assembled in logical sequence.

Briefly, the subjects covered include External Forces; Internal Forces; Problems in Design of Beams, Girders and Trusses; Joints and Connections; Graphic Statics; Columns and Structures. The author presupposes a knowl-

edge of mathematics, at least up to the beginning of algebra, and carries out the problems in a direct and simple manner. There is little theoretical material, but in the main it is such that the average draftsman will have no difficulty in following it. This is more especially true for those who are doing such structural work as tracing, etc. Knowing why will be of value to any draftsman, and will put him in line for promotion and the much-coveted raise.

While much of the book is intended for steel designers, there is a good deal of attention paid to such subjects as wood trusses and their connections, cast iron column bases, foundations and footings, etc.

Especial effort seems to have been made to give credit to the several engineers and designers who have developed formulas and methods. This gives value as combining the best thought of many minds on this one subject.

C. A. M.

Parallel Tables of Slopes and Rises, in Combination with Diagrams of Slopes and Rises and Other Tables. For Bridge and Structural Engineers, Draftsmen, Checkers, Templet Makers, Builders and Vocational Schools. By Constantine K. Smoley. First Edition. 332 pp. 5 by 7 inches, bound in flexible black leather, gilt edges. Price, $4.00. Published by McGraw-Hill Book Company, New York.

Nearly thirty years ago the author of this work prepared the well-known "Smoley's Tables," the aim of which was to meet the difficulties in the calculations required for bridge and structural work. Later editions of the work, of which there were eight, included tables to cover other fields of technical work.

The original tables, as well as those in the present book, meet two peculiar conditions found in bridge and structural engineering, two conditions not found in surveying and similar work. The first of these is that the linear measures used are expressed in feet, inches and fractions of an inch, instead of in feet and decimals of a foot, as, for instance, in surveying. The second feature arises from the method of measuring angles formed by the members and parts of a framed structure. The angular measure is replaced with the so-called bevel, which is the value of the natural tangent of the angle, expressed in inches, 12 inches or one foot being the unit. The Table of Angles and Functions Corresponding to Given Bevels, published in the third edition of Smoley's Tables, offered a comparatively simple method of solving a right triangle when one of its sides and the bevel of the hypotenuse were given, but the method still required considerable work before final results were secured. The present volume aims to eliminate entirely the work involved in solving such triangles and gives ready answers for the bevels and distances in common use. It will be apparent that while the main function of the book is to solve right triangles when the bevel is known, it really will be of more value to those who use it than the original volume. In explanation of this statement, consider that the preparation of structural drawings may be divided into two parts, the first being the dimensions and bevels of the members of the frame. When these are found, there remains the task of laying out the joints and determining the dimensions of the material. The tables and diagrams will be found perfectly adapted for this work, because in all joints the bevels are known.

It is interesting to note that the tables are a compilation of over 100,000 separate solutions of right triangles, and give the dimensions in thirty-seconds of an inch, for all triangles from one-sixteenth of an inch to twelve inches on the bevel up to twelve by twelve bevels, and for all lengths up to forty feet. As the pitch is often given as "one-fifth," and "30 degrees," tables using these bevels are also given, separately. The other fractional pitches can, of course, be readily found from the tables.

The several diagrams given are practically graphical extensions of the main tables, and will, no doubt, be found of value in many forms of calculations, as they give graphically, to the nearest sixteenth, the dimensions shown in the preceding tables, within certain limits.

Included with the tables of slopes and rises are a number of tables reprinted from "Smoley's Tables." These include Parallel Logarithms and Squares, varying by one thirty-second of an inch from zero to ten feet; Loga-

rithms and Squares by Intervals of One Sixty-fourth of an Inch, Graphic Solution of a Right Triangle, Angles and Natural and Logarithmic Functions Corresponding to Given Bevels, Multiplication Table for Rivet Spacing, and Decimal Equivalents from one thirty-second of an inch to twelve inches. The inclusion of these tables would make the volume complete in itself, but the author has given the most minute instructions for using the various tables and diagrams, and their application to structural joints, with many practical examples and formulas, especially with regard to structural details.

C. A. M.

Compressed Air Theory and Practice. By Elmo G. Harris, C. E. 192 pp. 6 by 9 inches, with illustrations, diagrams, tables, etc. Price, $2.00. Published by the McGraw-Hill Book Company, New York.

Compressed air has, to many, always seemed to offer no particular problems to the designer or the workman. That there are many points to be considered in the design and calculation of machinery using or compressing will quickly be seen by examining this book. The author, as Professor of Civil Engineering at the Missouri School of Mines, has classes in compressed air and hydraulics, and so is in a position to know the value of this subject.

While compressed air is subject to the same laws as all other gases, no gas can be so freely employed. This is both an advantage and a disadvantage, for workmen are apt to waste it, thereby causing a monetary loss. There can be no loss or wastage of the actual material itself. It all comes back, but it requires more power to again get it under control.

This book deals with the physical properties of air and treats in detail the problems regarding temperature, expansion, density, contained moisture, reheating and cooling, measuring, friction in pipes, etc. Other chapters treat of special applications of compressed air, air-lift pumps, receivers and storage of compressed air, fans, compressors, blowers, drill capacity, and other items connected with the subject.

Examples and exercises will give the reader an insight into the method of using the formulas presented, and make him familiar with some of the many problems which arise in designing compressed air plants. As a textbook the student will find practically everything necessary to instruct him on the subject.

It will be readily seen that a book written for the student and the designer will be unsuited to the engineer or plant superintendent who has not had a technical education, and yet there is much of value in it for anyone interested in the subject. The tables and diagrams are as instructive for one as for the other, and one can read the book without studying all the formulas which prove the author's contentions. One interesting page explains the Patent Office attitude toward the air-lift pump, which apparently violate established laws of physics, and yet the pump is doing good work every day, and its principles of design and operation are treated at considerable length.

C. A. M.

Reinforced Concrete Design Tables, a Handbook for Engineers and Architects, for use in designing Reinforced Concrete Structures. By M. Edgar Thomas and Charles E. Nichols. 208 pps. 4 by 7 inches, flexible black leather covers, gilt edges. Price, $3.00. Published by McGraw-Hill Book Company, Inc., New York.

Handbooks of the steel manufacturers have long been the standard for designers in steel construction, but there has been considerable hesitation about accepting any standards for concrete and concrete reinforcement. It is easy to see why this is. The shapes in which the reinforcement comes, the shapes and locations in which it may be used, the percentage of steel to concrete, the varying nature of the concrete, all introduced so many variables that there have been many formulas presented, dealing with general and specific cases, and all more or less subject to the judgment of the designer. This book is intended to fill the same place in the designers' library as the steel manufacturers' handbooks mentioned above. To meet the designers'

ideas it has been found necessary to cover a wide range of stresses, including those used by a majority of designers. All questions of assumption and method of design have been eliminated, and the tables may thus be applied to the design of any reinforced structure. Should the designer prefer to use his own methods, by means of curves, tables, etc., these tables will enable him to check his other figures quickly and independently.

Among the tables given we note, Coefficients for Slabs and Simple Beams, Logarithmic Curves, Bending Moments and Shear for Continuous Beams, Weights, Areas and Spacing of Bars, Weights of Concrete Members in Pounds, Slabs and Simple Beams, Tee Beams, Beams with Compression Reinforcement, Square Columns, Hooped Columns, Hooped Column Reinforcement, Vertical Column Reinforcement, Spacing and Percentages of Column Hooping.

Several pages are given to explanations of the various tables, with suggestions for their proper use, as well as examples worked out to indicate typical cases. Three separate methods of calculating the reinforcement for hooped columns are given, one a method permitting an arbitrary increase in the base concrete stress with fixed limits of hooping reinforcement, another based on Considere's recommendations and a third, in which the hooping is assumed to work at a fixed stress regardless of the concrete stress. These several methods permit the greatest latitude in design, and accommodate themselves to practically and specifications and building codes.

The book is clearly printed on thin paper and the flexible covers permit it to be carried about easily, although its greatest use will be in the office or on the draftsman's table.

C. A. M.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings.

Meeting No. 977, October 1, 1917.

This meeting was under the direction of the Entertainment Committee as a Ladies' Night, and was attended by about 100 members and guests.

Mr. C. B. Ball, Chief Sanitary Inspector for the City of Chicago, gave an illustrated talk on the subject of "Homes of Today and Citizens of Tomorrow," which proved to be very interesting and instructive.

Modern Feminine Dress from an Engineering Standpoint was discussed by our members and guests. In addition to this, we were favored with music, including the singing of an original song by James Noble Hatch, entitled, "The Flag Across the Sea." Refreshments were served.

Meeting No. 981, November 5, 1917.

This was the regular November meeting of the Society. In accordance with the provisions of the Constitution, the amendments which had been submitted for consideration were read and discussed, and certain additional amendments were proposed. Before taking final action, the meeting was adjourned to the evening of November 19th for further consideration of the amendments.

The paper of the evening was presented by Mr. O. P. N. Goss, Consulting Engineer, Seattle, Washington, on the subject of "Lumber and Lumbering from an Engineering Standpoint." The lecture was illustrated by lantern slides. The paper was discussed by Mr. Walter Buehler, Mr. Max Loewenberg, Mr. Bernard M. Lochard, Mr. W. W. DeBerard and Mr. D. W. Roper.

The meeting was attended by about 60 members and guests.

Meeting No. 982, November 12, 1917.

This was a meeting of the Bridge & Structural Section and there were present 35 members and guests.

The paper of the evening was presented by Prof. H. M. Westergaard, Instructor of Theoretical and Applied Mechanics, University of Illinois. The subject was "The Resistance of a Group of Piles," and this subject was discussed by Mr. Dalstrom. There was also a moving picture illustrating the "Shifting of Foundations of High Buildings."

At this meeting, the proposed new rules for the Bridge and Structural Section were read.

Meeting No. 983, November 19, 1917.

This was a meeting of the Mechanical Section. A paper was presented by Mr. C. W. Bradley, Gas Engineer of the Public Service Company of Northern Illinois, on the Subject of "Manufacture and Distribution of Gases." The subject was presented in a very interesting manner and was discussed by the Chairman, Prof. G. F. Gebhardt, Messrs. James N. Hatch, Hubert V. Stephenson, E. J. Fowler, J. W. Lowell, Jr., R. F. Schuchardt, A. C. King, William E. Williams and Joseph H. Prior.

Following the paper of the evening, the adjourned meeting to consider the amendments to the Constitution. was convened with Mr. D. W. Roper, Vice-President, in the Chair. Various amendments and proposed amendments were submitted and approved for submission to the membership by letter ballot.

The proposed new rules for the Mechanical Section were read and referred to the next meeting of the Section. The meeting was attended by about 50 members and guests of the Society.

November, 1917

Meeting No. 984, November 26, 1917.

This was a joint meeting of the Electrical Section of the Western Society of Engineers and the Chicago Section of the American Institute of Electrical Engineers . Teh paper of the evening was presented by Mr. Bert H. Peck, M. W. S. E., Electrical Engineer of the State Utilities Commission, Springfield, Illinois. The subject was "Engineering Data Necessary for an Electric Rate Determination." The paper was very comprehensive and set forth the principles of the Illinois Commission in matters of this kind. Discussion of the paper was participated in by Messrs. C. A. King, E. J. Fowler, W. A. Show, J. G. Wray, R. F. Schuchardt, K. B. Miller and J. H. Prior.

Mr. R. S. Hatch presented a statement and important engineering subjects which had been presented in the current engineering literature during the past month.

The proposed new rules of the Electrical Section were presented as amended by the Executive Committee, and on motion were approved.

ERRATA.

The Secretary begs to correct the numbers of the meetings reported in the October Journal: No. 978, October 8, 1917; No. 979, October 15, 1917; No. 980, October 22, 1917.

EDGAR S. NETHERCUT, Secretary.

Journal of the
Western Society of Engineers

Vol. XXII DECEMBER, 1917 No. 10

CONSTRUCTION OF CANTONMENT AT CAMP GRANT

By Chas. B. Burdick, M. W. S. E.

Presented Dec. 3, 1917.

There was nothing novel in the construction of the army cantonments, so far as the work itself was concerned. Throughout this work it was the endeavor to follow well established lines of construction only. Novelties received no consideration, for there was no time for study or experimentation. Camp Grant is typical of sixteen divisional camps, and in many respects it is similar to a like number for the National Guard.

A description of the work in itself, therefore, would not be instructive, and will be followed no further than is required for a general understanding of the problem. The interest to the engineer lies rather in the plan of procedure by which our National Government, usually so deliberate in all its movements, found the means to construct so great a work in so short a time. It will be the effort, therefore, to describe briefly what was done; to indicate the rate of progress; and to outline the procedure that made speed possible.

THE CAMP

Camp Grant is located at the junction of the Rock and Kishwaukee Rivers, five miles below the center of Rockford, Illinois. Rock River forms the western boundary of the tract comprising 5,620 acres, or about nine square miles. The Kishwaukee River bounds it upon the south. The site lies 30 to 50 feet above the rivers. The soil is a sandy loam underlaid by sand and gravel to a depth of 100 ft. or more.

The larger part of the reservation is devoted to the rifle range and maneuvering ground. The camp proper occupies a site about three miles north and south, by one and one-half miles east and west. Quarters are provided for 42,000 men and 10,000 animals. There is a total of 1,520 buildings, all of wooden construction, ranging in size from 60 ft. by 160 ft. for warehouses, down to about 14 ft. square for the smaller lavatories adjacent to officers' quarters. The greater number of buildings are the company barracks, which are

two-story structures 43 ft. by 140 ft. Most of the officers' quarters are 20 ft. by 112 ft. All buildings are of frame construction, the walls consisting of siding and tar paper outside the studding, with an interior lining of compo-board on walls and ceiling.

Fig. 1. Plat of Camp Grant.

Each barrack is provided with a lavatory corresponding in size to the accompanying barrack. Each lavatory contains water closets, shower baths and washing sinks. Hot and cold water is provided.

UTILITIES

The camp is provided with a water supply reaching each building and furnishing fire protection. The streets and the buildings are lighted by electricity. The greater part of the barracks are steam heated by a large number of central heating plants supplying the steam through covered pipes supported on poles. The more isolated buildings are heated by stoves.

Where steam is available, the water for washing in the lavatories is heated by steam. In the isolated lavatories coal heaters are used.

WATER WORKS SYSTEM

The water supply is obtained from six wells 10-in. in diameter and ranging in depth from 154 ft. to 185 ft. The water is drawn from a coarse sand stratum through Johnson brass strainers from 15 to 20 ft. in length.

The water is pumped from the wells by the air lift system, under a head of about 45 ft., to a circular concrete reservoir containing 300,000 gallons, from which the high lift pumps draw the water and deliver it to the distribution system. Air is supplied by three electric driven two-stage short belted Ingersoll-Rand air compressors, at present operating at about 60 lbs. air pressure.

The high lift pumps are electric driven with the exception of one oil engine unit provided for emergency service. The station contains four electric driven centrifugals having a capacity each of 1,000 gallons per minute against 180 ft. head. There are two Alberger pumps direct connected and one American Well Works pump belted to a motor. The oil engine unit is an 80 horse power Charter engine driving an American Well Works centrifugal pump, having the same capacity as the electric units.

DISTRIBUTION SYSTEM

The distribution system contains sixteen miles of water mains ranging from 6 in. to 12 in. in diameter, and 20 miles of service pipes from 3 in. to ¾ in. in size. About half of the water mains are wood stave pipe, manufactured on the Pacific Coast.

A steel elevated tank containing 250,000 gallons and 140 ft. in total height is connected to the distribution system, and furnishes a reserve supply to tide over the peak of water consumption and to furnish a reserve for fire protection.

SEWERS

The ordinary summer flow of Rock River is from 1,000 to 2,000 second feet. This dilution was deemed sufficient to accommodate the sewage of the camp without nuisance and, therefore, it was not considered necessary to construct works for sewage purification, particularly in a camp to be operated for an uncertain time. The river also receives the unpurified sewage of Rockford, 60,000 people, as well as other smaller cities. The sewer system aggregates a total

of 27 miles, and consists of vitrified pipes ranging from 6 in. to 24 in. in diameter. Nothing could be accomplished by bringing the sewage to one place. Dilution was facilitated by a number of outlets, and this minimized the depth of cutting that was required. About one-third of the camp drains through a 24 in. main sewer entering the Kishwaukee below the reservation. The northern two-thirds of the camp reaches Rock River through seven outlets.

ROADS

The road system aggregates twenty miles. The appropriation for this purpose was quite limited, and as a gravel road of local but comparatively untried material could be constructed for about one-quarter the cost of water-bound macadam, the latter was only adopted for the principal roads, totaling eight miles. The remainder of the road system is of gravel consolidated by traffic. Naturally the gravel does not contain sufficient cementing material. This was obtained by utilizing loam existing at the side of roads as built.

RATE OF PROGRESS

The preliminary instructions required that the camp should be ready to receive the draft army, 37,000 men, on September 1st, and further, should accommodate the first contingent of officers about August 20th. Subsequently, we were advised that the first contingent of the draft would arrive, 5% September 5th, 40% September 19th, 40% October 5th, and 15% thereafter. This schedule was followed approximately.

The writer first visited the site on June 18th in company with his associate, Mr. John W. Alvord, and Mr. E. H. Bennett, consulting architect. We were accompanied by a sufficient number of men and instruments to place three survey parties in the field. At this time the site had not been officially selected.

Within the following three days, the cantonment had been tentatively located, and the general plan of water supply and sewerage had been settled. All these plans were modified in minor respects as the work progressed, but in their essentials they remained unchanged.

On June 22nd the site having been officially selected, the constructing quartermaster and the contractor arrived on the ground and immediately began the erection of the construction camp and the switchtrack connections for the supply of materials. By the 10th of July the construction of the barracks was in full swing, and a sufficient number had been completed to furnish housing and offices for the construction force, the engineers, constructing quartermaster and the field auditor, with their helpers.

By July 5th the pumping equipment had been selected and within a few days thereafter was under contract. On July 10th the first trenching machine began work upon sewer ditches. On July 15th the first of the permanent wells was started. Until late in

August the construction force was supplied by three shallow temporary wells.

The number of trenching machines was gradually increased up to eight, and as water pipe had not arrived, the work was concentrated on the sewer system. On August 10th sewers were 75% completed. The average progress in the construction of trenches for water works and sewers reached 4,000 feet per day for the first forty days. The average progress per machine was as follows:

Average feet per day per machine........................ 545 ft.
Average progress of best machine........................ 755 ft.
Best day's work for one machine..........................1,700 ft.

Nearly all the cuts ranged from 3½ to 6 feet, and probably averaged 4½ to 5 ft.

During July, August and September, several material additions to the works were made, including the base hospital, involving

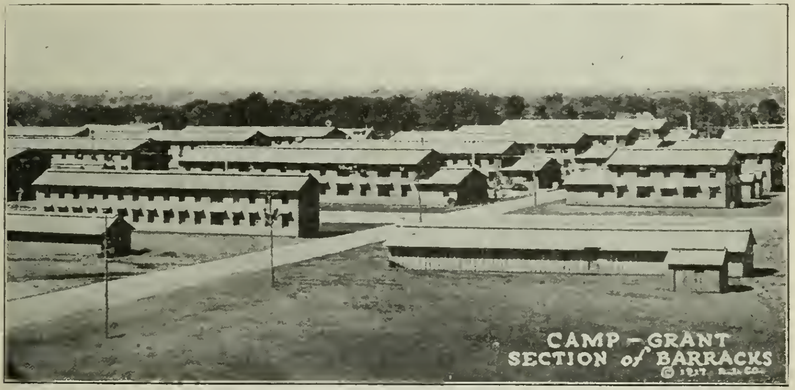


Fig. 2. Typical View of Army Barracks.

some sixty buildings, the remount station, the ordnance depot, the rifle range, and quarters for the training battalion, housing some 6,000 additional troops. All these additions involved increases in the road program and the water pipe and sewer systems. For these reasons, although the camp was ready to house the draft army when sent, construction work was not entirely suspended until November 30th. On this date the camp was turned over to the army.

ELEMENTS OF SUCCESS

Our government has always been very deliberate in its movements. Government construction in peace-time has followed a routine which experience has indicated was necessary to safeguard the public interests. Under this system speed has been an impossibility.

In the cantonment construction red tape was entirely eliminated. In fact, it may be said that authority was more direct than usually is the case in the work of private corporations. In no other

way could the draft army have been accommodated in the time between the availability of appropriations and the mobilization of the first contingent. In the writer's opinion, the rapidity of construction is directly attributable to four things, namely:

1st. A set of standard instructions that defined what was to be done, with clearness and yet with sufficient elasticity to accommodate local conditions.

2nd. A good general contract on a cost plus percentage basis.

3rd. A constructing quartermaster in each cantonment practically with supreme authority.

4th. The use of existing and experienced organizations as far as possible.

INSTRUCTIONS

In reference to the instructions, it should be remembered that accommodations for an army was a new thing to everyone on the work. It was imperative, therefore, that the instructions should be of such a nature that men familiar with general construction could proceed at once to build that which the army would require.

The written instructions included about 100 pages of typewritten matter accompanied by a set of blue-prints showing a typical camp arrangement, a drawing for each type of building that would be required, and typical outline plans of the water pipes, sewers and roads. On the typical plan the camp was divided into units or blocks 430 ft. wide by 660 ft. deep, upon which a typical location for buildings was shown for each kind of army unit, as infantry, artillery, etc. It was the duty of the engineers and the consulting architect to adapt the typical plan to the site selected, taking into consideration the orderly arrangement of the units, the topography, the railroads, the highways leading to the camp and a multitude of other considerations. The instructions further provided the amount of water that should be supplied and the amount of sewage that would reach the sewers. The plans and instructions were by no means sufficient to construct the work, but they furnished a very definite basis on which to design the work. They bore evidence of the very careful and capable study that had been given to the problem between the declaration of war and the time that the work was placed in the hands of the construction force.

GENERAL CONTRACT

The general contract was on the well known cost plus percentage plan. The contractor was remunerated for all costs, not including his overhead expenses. Sub-letting was not allowed except by special permission. The contractor was remunerated for all equipment and the contract provided a rental basis upon which any necessary equipment could be secured. A long list of maximum rentals accompanied the contract, and where particular kinds of equipment needed were not listed, the general spirit of the list was followed. A clause was provided whereby the government could purchase rented

equipment at the close of the work under a reasonable arrangement, whereby rental paid could be applied on purchase price.

The general contract was awarded to Bates & Rogers of Chicago, a firm having made a reputation for success in heavy construction, both on government work and upon a large amount of railroad work in all parts of the country. The principal officers of the company were resident upon the work during the inception and throughout the critical stage of construction, and their large and capable organization was expanded by the loan of men from other organizations and by large additions to their supervising force otherwise secured.

Fig. 3. Nearly All the Trenches for Water Pipe and Sewers Were Excavated With Trenching Machines

CONSTRUCTING QUARTERMASTER

Major Donald H. Sawyer, Q. M. R. C., previously a civilian engineer at Spokane, Wash., a member of the firm of Sawyer Brothers, practicing engineers in municipal work, filled the office of

Constructing Quartermaster at Camp Grant. The Constructing Quartermaster was the center of authority in which every move necessarily originated. Every plan, every order, every adjustment of wages, every arrangement for railroad service, all the contracts and agreements for the acquirement of land, the purchase of power or any other expenditure necessarily passed through the office of the Constructing Quartermaster. It was his business to insure the completion of the work on time as economically as possible.

He was given the power to buy where he could and at what price he could, subject only to certain necessary restrictions where Washington found it necessary to mobilize practically the entire resources of the country in certain lines. He was required to instruct the contractor where to buy and at what prices. He was not required to take bids. The time available would not permit of it. Quite properly the government exercised extreme care in the selection of these quartermasters, and the results speak for themselves as to the integrity and ability of the quartermasters selected.

Those not actively connected with the work can hardly realize the multitude of decisions necessarily made during the first month of the work, the inevitable confusion incident to a green organization of active men, and the multitude of applicants for the attention of the quartermaster and his subordinates. The work necessarily required a man of broad construction experience, with intelligence to see a point quickly, with the perseverance and the constitution to stay with the work 18 hours a day during its early stages, with discernment to pick out the true story from the false, with the patience to wait when he could wait, and the boldness to stretch his instructions if necessary, and with all, to accomplish these things with a good humor that retained the friendship of every man on the job, held him to his task and demanded his best effort. With a few exceptions, the constructing quartermasters were civilian engineers, and if the results at Camp Grant are typical, and the results at the other cantonments indicate this probability, the engineering profession has the right to be proud of the men selected as constructing quartermasters.

ENGINEERS

The instructions to the quartermaster empowered him to employ such engineering assistance as he might require, and outlined terms under which such assistants might be employed. Provision was given to organize an engineering force *de novo,* or to employ an engineering organization already created; furthermore, provision was given to employ individuals and organizations for various specific tasks, and the last practice was followed at Camp Grant.

Mr. E. H. Bennett, consulting architect and town planner (with his organization) was employed in reference to the general plan of the cantonment and the specific problems relating to his specialty; and the writer's firm, Alvord and Burdick, collected the topography, co-operated with Mr. Bennett in the layout of the camp and planned and supervised the water supply, sewers and roads. Mr. W. L.

Maloney of Spokane, Wash., was in charge of building construction and electric lighting. The Arnold Company of Chicago planned and supervised the steam heating installation. Mr. F. E. Morrow was loaned to the quartermaster by the C. W. I. & Belt Railway of Chicago to assist the quartermaster on railway matters, particularly a subway and an overhead crossing required that troops might pass the railways between the camp and the maneuvering field.

FIELD AUDITOR

The general plan of organization provided for the field auditor appointed by Washington, who should check all materials received, keep the time on all forces employed, and with the quartermaster

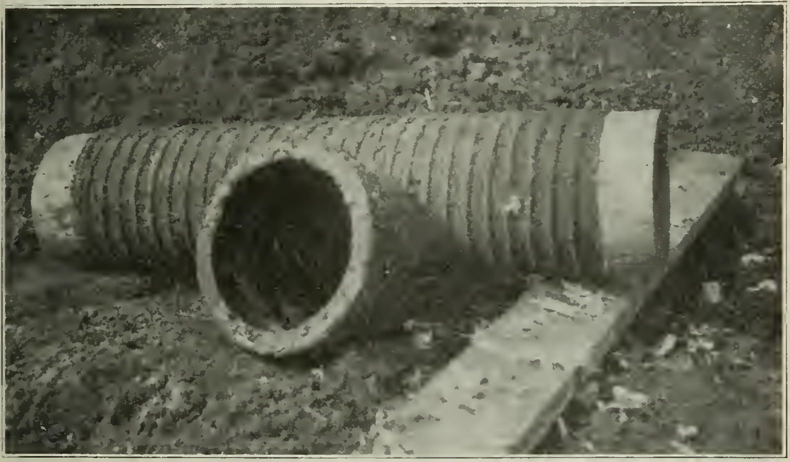


Fig. 4. About Half of the Water Mains Consist of Wooden Pipe, of Which the Picture Illustrates a Short Section.

should certify to all payments. To accomplish this purpose a large force of bookkeepers, timekeepers and checkers necessarily were employed. The field auditor was Mr. E. B. McGwinn of Chicago.

USE OF ORGANIZATIONS

It will be observed that the overhead force was an organization of organizations, so to speak. It is believed that, to a large extent, this accounts for the rapidity with which the work reached top speed. It hardly needs to be said, however, that all these organizations were greatly expanded during the work, but there was a nucleus of experienced men accustomed to the methods of their organizations into which new men could be fitted with a minimum of delay in the assignment of the right man to the proper place.

PURCHASING

It has been said that the constructing quartermaster was empowered to use his judgment in regard to purchases, subject to

certain restrictions. These restrictions related principally to materials that were difficult to secure in the quantity required for the great amount of government work simultaneously prosecuted. It will readily be appreciated that with thirty-two quartermasters, thirty-two contractors and a still larger number of engineers, all making inquiries for materials at once, manufacturers would be at sea on the matter of prices and practicable deliveries. Very early, therefore, it was recognized that in certain instances materials necessarily would be mobilized by the cantonment construction division at Washington.

Lumber, pipe, boilers and plumbing equipment and some other materials which were demanded at such a rate as to exhaust existing

Fig. 5. Water Works Pumping Station Reservoir.

stocks and which required the entire manufacturing capacity of all concerns in the business, were early mobilized through the Washington construction division, and materials were reserved by them to be ordered from certain manufacturers at stated prices by the contractor under order from the constructing quartermaster. At a later date electrical equipment and pumping machinery was similarly mobilized and reserved. In general, the prices paid were lower than similar materials could be bought for in the open market by private individuals.

In another respect the dealings between the government and producers was unique. No written guarantees of any kind were required as to the excellence or time of delivery of any equipment. Only manufacturers of established reputation were dealt with. The manufacturers were given clearly to understand what was required in the way of service and delivery. They were asked to state their

price and their time of shipment. The order was placed with the understanding that the manufacturer would make good. No penalty of any kind was asked. To the credit of the manufacturers it can be said that almost without exception, that which was furnished met the requirements, and in no case was delivery delayed sufficiently to materially affect the building program.

DEVELOPMENT OF PLAN

When it is realized that the working plans and actual construction was begun and carried on simultaneously, the task of those

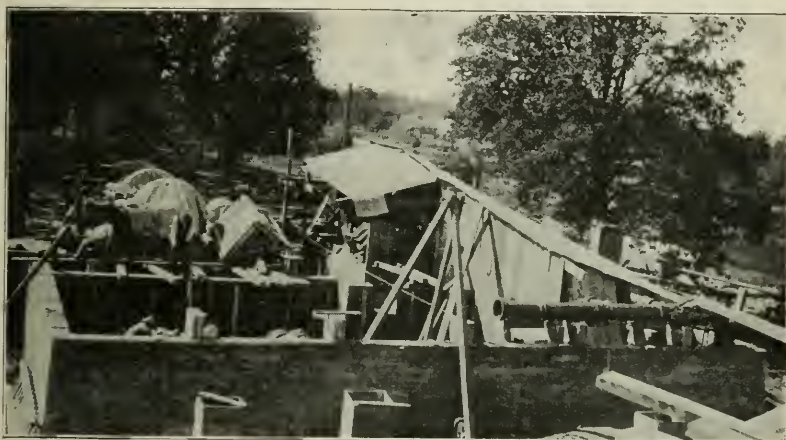


Fig. 6. The Pumping Equipment Was Installed and Began Its Operation Before the Building Superstructure Was Complete.

charged with design will be appreciated. For the first few weeks the engineering force staked out the work during the day, and planned for the next day during the night. In general, specifications were avoided. It was the effort to simplify the plans as much as possible and to make the drawings contain the greater part of the instructions required to a capable constructor. Many of the instructions were necessarily carried by word of mouth, and the engineers soon came to realize the value of a plan prepared in advance in the saving of effort and the certainty of results. The engineer with a plan in his head could not be everywhere, and it is astonishing how frequently it was found that after the delivery of instructions again and again, someone who had not had the benefit of instructions would actually do the work. This was particularly noticeable in the early stages of the work.

Although Washington provided typical plans for all buildings, these plans had to be redrawn and detailed to be successfully carried out by carpenter foremen. Until details were worked out on paper, many differences of opinion developed in reading the plans, and

errors would creep in as to the location of windows and doors on right and left-hand buildings, for many of the buildings were duplicates, except that they were reversed in plan. Construction did not await the preparation of these detailed drawings, but proceeded by word of mouth pending working drawings.

In the construction of the system of wells for the water works no time was available to explore the underground conditions by test wells to determine what would be required as to well strainers, casings and well pumping equipment. It was necessary to anticipate all possible conditions and to place orders for all well casings

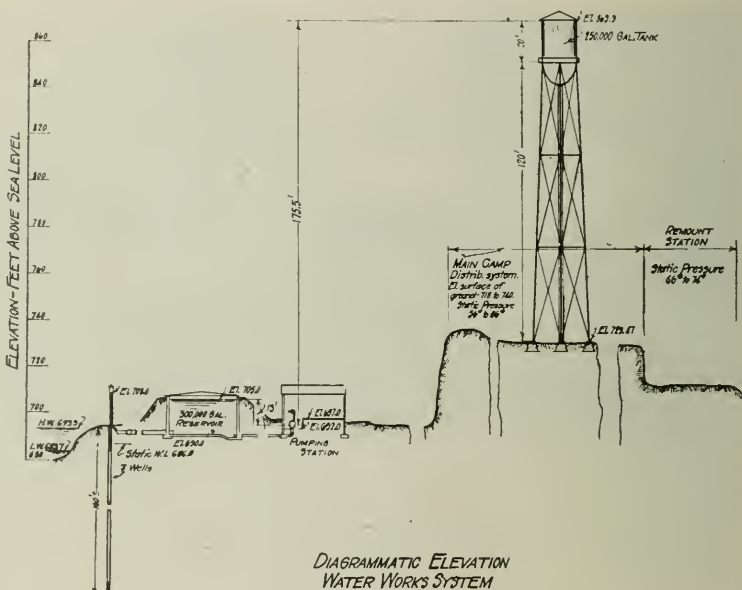


Fig. 7. Diagrammatic View Illustrating the Water Works System.

and well drilling equipment that would possibly be required.

Experience in northern Illinois made it certain that a supply of water could be obtained in the St. Peter sandstone with wells about 500 ft. deep, but the time required to drill to this depth made it desirable to develop the water in the sand and gravel overlying bed rock, if this could be done. Experience in the City of Rockford was not favorable to these shallow wells. Therefore, it was not considered safe to make plans for a supply nearer the surface than the St. Peter sandstone. Accordingly, casings and well drilling equipment were mobilized for deep wells. At the same time accurate records were kept of the strata encountered from the ground surface, and a strainer was provided, so that if favorable materials were encountered, the strainer could be set and a well test could be made. Fortunately, the shallow supply was successful, and with the

first successful well, additional strainers were provided and used in the remaining wells as rapidly as the drill rigs reached the water bearing sand.

Likewise in the design of the pumping equipment, provision was made for every contingency reasonably possible. In the light of developments, it would be possible to develop a supply by suction. It was known that this could be done before the work started, but if it had been necessary to develop water in the St. Peter sandstone, the supply per well by suction would have been so small that a large number of wells would have been required, thus defeating our purpose through the consumption of too much time. Furthermore, as a proposition for water supply during the period of war, it would be economy to construct a few wells and pump them deep, rather than a larger number of wells pumped by suction to a shallow depth.

For this reason, and further on account of its reliability, the air lift pumping system was adopted, and it was so designed that the desired supply could be pumped from a depth of 100 ft. if necessary. Fortunately, capacious wells in the sand and gravel permit of the required supply with a lift of about 45 ft., and, therefore, there is a reserve of capacity in the air lift pumping equipment in addition to one compressor unit held in reserve for breakdowns.

It must not be assumed that the work was carried through without difficulties or disappointments. This was far from the facts. Although everyone tried to anticipate difficulties and provide for them in advance, there were few days during the first six weeks when something wholly unexpected and detrimental to progress did not arise. Space will not permit us to record them here, but they were real difficulties at the time, and that some of them did not defeat the purpose of the work is due to the credit of the superintend ents and foremen who displayed great resourcefulness in emergencies.

Early in the work, before everyone's powers and duties were clearly understood, there was much in the way of chasing up blind alleys and coming out again before the right path was found. It was surprising, however, the good nature displayed by everyone in these encounters. In fact, it was a feature of the work from first to last, that in case of error, everyone searched for the remedy rather than a "goat" to place the blame upon, and it was this spirit among the men engaged that made this strenuous work a pleasure.

DISCUSSION

Mr. Samuel A. Greeley: Mr. Chairman, and Gentlemen: I got in, unfortunately, after Mr. Burdick had made his talk on the work at Camp Grant, and as his work there was the water supply and sewerage work and as my work at Camp Custer was also the water supply and sewerage work, I, of course, am not able to discuss what he said, but I heard Mr. Burdick talk once before on Camp Grant, and I know that he has given you a very complete description of what happened at Camp Custer, because the canton-

ments are so similar and I find that a great many of his individual experiences were so similar that the two stories fit very closely, and there isn't a great deal that can be added by way of individual detail unless you go pretty extensively into the construction, and as the hour is late, I do not, of course, want to do that.

Camp Custer is located just off Battle Creek, four and a half miles, and at the start, beginning with the middle of June, had four available sources of water supply that we looked up. One was the filtered water supply from the Kalamazoo River, another was the connection with the Battle Creek supply, the third was the development of some small lakes adjacent to the Camp, and the fourth was a well water supply from the Marshall Sandstone. Obviously the well water supply offered the safest water, and if it could be developed near enough to the Camp in sufficient quantity, it offered the best possibilities.

Looking into the geology of the Marshall Sandstone, from which the best available water supply comes in that district, it was found that the camp site happened to be located just at the southerly fringe of this formation, and as the geological maps and records did not show exactly where that southly fringe was, it was necessary to get busy with test borings in order to find out whether we could find a sufficient thickness of sand near enough the camp site to develop a sufficient supply of water, and that was the principal problem at the start of the water supply construction.

We were able to find a thickness of roughly fifty feet of the sandstone within a mile of the camp. Unfortunately the location came north of the Kalamazoo River, while the camp site was on the south side of the Kalamazoo River and that necessitated the construction across the river bottomlands of either side of the rivers, which was not as easy work as it would have been if we could have located the well supply on the same side of the river as the camp.

The water supply was developed from these wells, eight ten-inch wells being put down to a depth of about one hundred and twenty feet. Three well drilling rigs were put to work and they averaged approximately eighteen feet per day per machine, driving a ten-inch casing through fifty or sixty feet of glacial gravel and eight to ten feet into the standstone, and then chiseling out of a hole ten inches in diameter, through the sandstone. The water is lifted through the wells by vacuum pumps, through centrifugal pumps which pump it across the river to a hill adjacent to the camp; eight hundred thousand gallons of storage, sufficient to give a pressure of about one hundred feet, which is boosted at a booster pumping station adjacent to these tanks and distributed through the camp.

The Camp is built in the shape of a bow, strung out over a length of about three and one-half miles, and in order to give sufficient pressure we had to increase the pressure at these storage tanks. We used, as was the case in very many of the cantonments, the wood stave pipe for the water distribution. Our average rate of progress with the wood pipe and the trenching machine of the Parsons type

was about seven hundred thirty feet per machine per day, the maximum of course running up to practically double that.

Our connections between the wood pipe and the iron fittings and valves were something new to us and quite a problem and we finally were able to get all the bells of the castings and the tees to fit the spigots of the wood pipe.

In regard to the sewerage. The camp is located along the Kalamazoo River at a height of perhaps fifty to sixty feet or more above the river, so that there was ample fall from the camp to the river. There was high ground between the camp and the river with two cuts through, so that we only had two outlets to the river and this necessitated careful planning with minimum grades in order to keep the depth of the sewer at a practical maximum of about eleven feet. The group of cuts of course slowed up the work. Also in the soil which we had, which was a running sand, which would not stand readily without sheeting below four or five feet with a depth added to it or increased the difficulty of making speed. After trying out sheeting, which we found too costly and too slow, we finally sloped the banks of the trench back about one-third horizontal to one vertical and threw the burden of the work on the machine and kept the sewer pipe very close to the trenching machine and in that way struck what was the best way to progress. It averaged about three hundred and fifty feet per day per machine on the sewer work.

The sewerage was discharged into the Kalamazoo River. The Kalamazoo River is not used as a water supply anywhere, but it already had the sewerage of something like one hundred thousand people discharged into it, and the State Board of Health had negotiations under way with a number of the towns for some treatment of the sewerage and we felt that it was better to give a moderate amount of treatment through settling tanks of the typical type planned by the Cantonment Division in Washington. The cost of the two tanks was around $30,000, which was quite a large proportion of our total and they were so arranged that we could use the sewers before the tanks were completed, and they did not delay the use of the sewers by the troops as they came into the camp.

ARMY CANTONMENT CONSTRUCTION AT CAMP MEADE, MARYLAND

By N. B. Garver*

Presented Dec. 3, 1917

INTRODUCTION

The organization of a force of men sufficient to secure materials and to erect a plant costing several millions of dollars, within a period of 90 days or less, requires the highest type of engineering skill. American engineers have been called upon to perform this

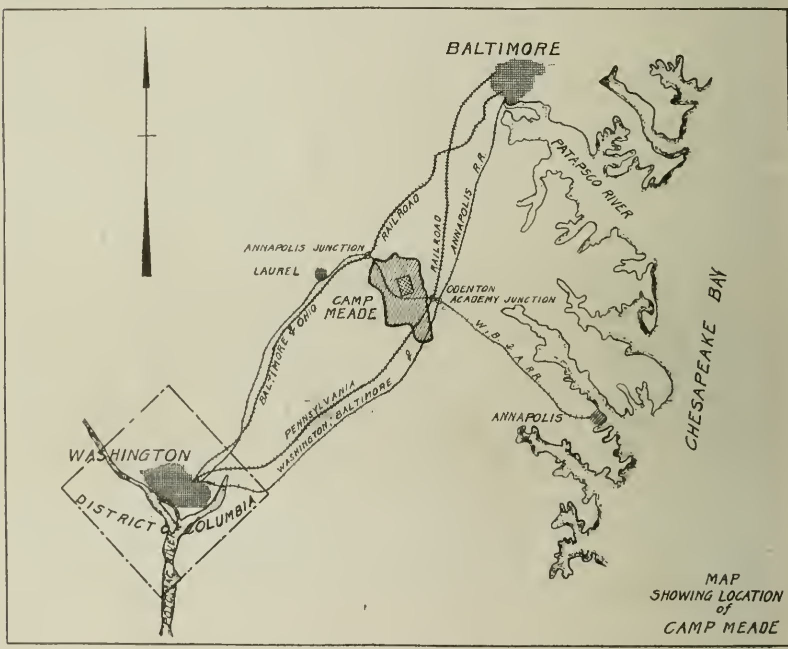


Fig. 1. Map Showing Location of Camp Meade.

task during the past summer, and we are pleased to say, have "made good."

The problems in building construction which the engineers have been called upon to solve are not those involved in technical design; nor in determining the properties or composition of materials; nor in the preparation of intricate plans. Their solution does not depend upon a knowledge of higher mathematics, nor on a very exact knowledge of the mechanics of materials.

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The success of the enterprise *does* depend upon the ability of the engineer to judge and manage men. There is no mathematical formula by which the efficiency of a workman may be determined, but the engineer of such an organization must have its equivalent tucked away somewhere in his brain if he is to succeed. He must be a human engineer, if you will.

Men of experience must be secured to take charge of each of the numerous branches of the construction work and push them with zeal. They must not only be able to build, but must build rapidly.

Fig. 2. A View of the Cantonment Grounds, Taken from One of the High Points.

Time is a governing factor, and the individual who does not realize this fact must make way for the one who does.

The construction of a cantonment is a large undertaking. Except for those few individuals who have direct charge and who visit practically all parts of the work each day, it is impossible for any one person to keep in touch with and know of the progress in departments other than that in which he himself is employed. For that reason no attempt will be made here to cover the work of construction outside of the general organization, the handling of materials, and building erection.

THE CAMP SITE

Camp Meade, Maryland, is located about midway between Washington and Baltimore. The area included within the cantonment grounds comprises about 8,000 acres, or a little more than 13

square miles. The buildings, which consist of barracks, officers' quarters, schools, administration buildings, medical buildings, store houses, stables, gun sheds, etc., a total of about 1,600 buildings, cover an area of probably four square miles.

The camp site was furnished by the State of Maryland and cleared by them at an expenditure of about $150,000. Before con-

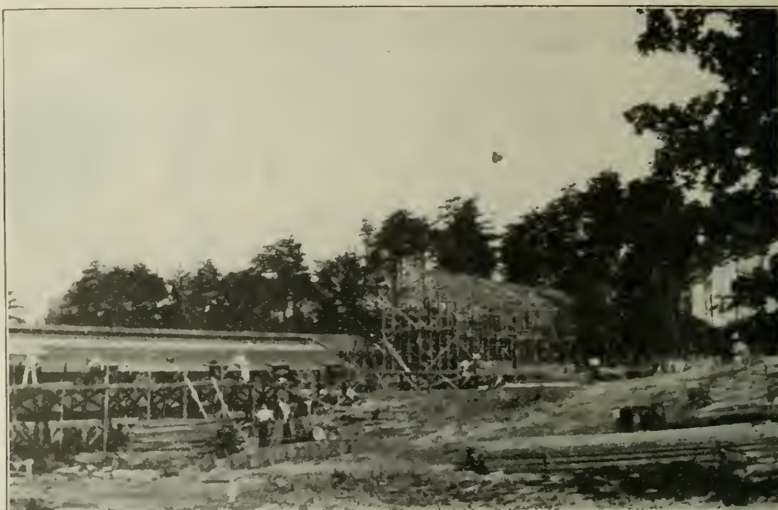

Fig. 3. All Trees Whose Trunks Were Eight Inches or More in Diameter Were Left Standing.

struction work began this area was covered with scrub pines and underbrush, except for clearings here and there, which were planted to strawberries, sweet-potatoes, beans, tomatoes, cucumbers, and crops particularly adapted to that soil.

The soil is very sandy; so much so that it does not become muddy even after the heaviest rain storms. The water sinks into the soil and disappears almost as rapidly as it falls. This quality is desirable for a camp site, but from the construction standpoint it presents difficulties which are not easily overcome.

The drainage of the camp site was a simple problem. The sandy soil and the natural water courses, combined with the rolling surface, left little to be desired from this standpoint.

ORGANIZATION

General Organization.—The contractor's general organization is shown on the diagram, Fig. 4. This, of course, gives only the major sub-divisions of the work. The interior plumbing and the electrical work were placed in charge of a firm of Baltimore contractors.

The titles for other departments indicate the nature of the work

over which each had control. For example, the sanitary department was responsible for the health and sanitation of the construction camp. It provided medical service for all employees who became ill, or were injured; kept careful watch on the supply of drinking water; saw to the proper disposal of garbage; required the construction of sanitary cess-pools for the disposal of liquid kitchen wastes, regulated the location of temporary latrines; looked after the drainage of stagnant pools of water to prevent the breeding of mosquitoes; and provided proper bathing facilities.

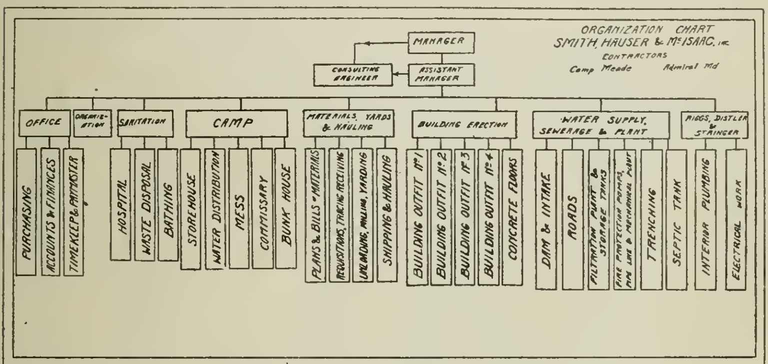

Fig. 4. Organization Chart of Smith, Hauser & McIsaacs, Inc., Contractors for the Cantonment Construction at Camp Meade.

Building Outfit. The erection department was divided into four building outfits and one concrete outfit. Each building outfit had its own organization, the nature of which was dependent upon the ideas and methods of the superintendent in charge. The organization of Building Outfit No. 2 is shown on Fig. 5. There was a timekeeper's and pay office, and a force of material checkers, in addition to the three general foremen's organizations. Each general foreman had from 6 to 12 carpenter foremen, each of whom had from 15 to 40 carpenters. He also had one or two labor foremen with laborers.

Effort was made to provide about 6 laborers for each ten carpenters, but without any marked success. Laborers were scarce and such as were to be had were of low grade.

Development of Men. One of the most interesting diversions in connection with this work was to watch the growth of the organization and the development of the men in it. Months were not required to determine a man's capabilities. His fate was usually determined within a few days. There was no such thing as drifting. It was a case of sink or swim; fish or cut bait. For example, a man employed as superintendent of a building outfit did not have the necessary initiative and at the end of the week had accomplished

little. He was discharged and another, taking his place, at the end of one week was erecting 75,000 feet of lumber per day.

TRANSPORTATION FACILITIES

Railroad. The transportation of materials was, of course, a matter of primary importance. The camp site is situated between two trunk line railroads (see map of location Fig. 1), which are probably 6 miles apart at this point, the Pennsylvania Lines on one

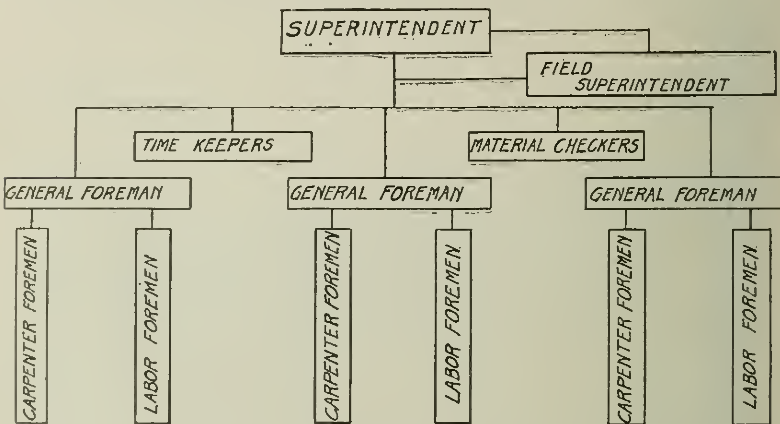

Fig. 5. Organization Chart, Building Outfit No. 2, Camp Meade, Admiral, Md.

side and the Baltimore and Ohio Railroad on the other. Neither of these was near enough to the points where construction was in progress to permit unloading of cars without their transfer to a lightly constructed electric line which traversed the camp site. Both steam railroads began the construction of extensions to the camp, but the work was not pushed with sufficient speed to justify waiting until these extensions were available. All cars of material were transferred over the tracks of the electric line by the use of steam locomotives. New ties and heavier rails were put in place to avoid inconveniences and delays due to derailment.

Yarding. There were no yarding facilities worth mentioning on the electric line, so it was necessary to construct yards to provide for the handling of 50 to 75 cars of material daily. Three yards were provided at points convenient to the work, as shown on Fig. 6. Yard 1 was located at Disney; Yard 2, at Portland; and Yard 3, at Admiral.

Classification. The materials were classified as illustrated by Fig. 7 the bill of material for the 200-man Barrack. All dimension material was unloaded at Yard 1; all one-inch boards at Yard 2 and all miscellaneous materials at Yard 3.

Some difficulty was encountered in getting each class of material to the proper place because some cars would contain a mixed lot.

Hauling. Practically all hauling from the yards to the building units was done with teams. There were many heavy motor trucks in use, but they were chiefly employed in hauling road materials. The heavy trucks were of little value when taken off the improved

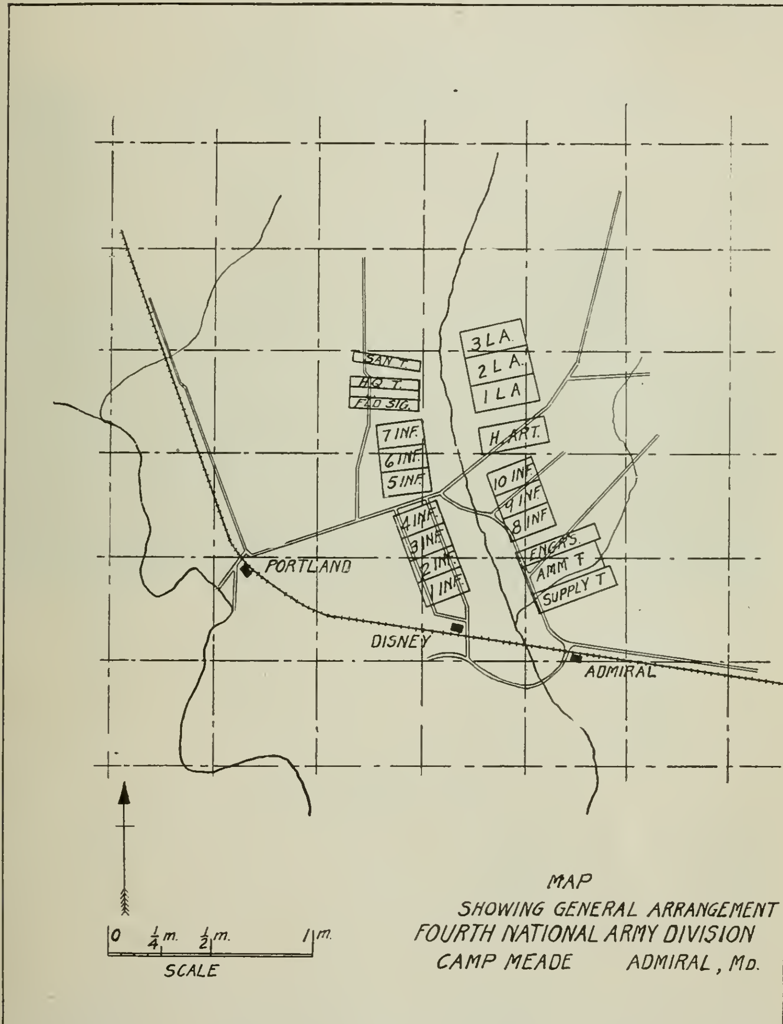

Fig. 6. Map Showing General Arrangement of Units at Camp Meade.

roadways because of the loose, sandy soil. Numerous light trucks, about 1½ tons capacity, were used to good advantage in hauling light loads, or in securing small quantities of materials which were wanted quickly.

December, 1917

At the beginning of construction, before the roads were improved, 500 feet of lumber made a full load for one two-horse team. Later, when the roads had been improved with a layer of clayey gravel, each team could haul 800 feet if a snatch team were used to help over the worst places.

200 MEN COMPANY BARRACK 43 x 140

FOREMAN AND CHECKER'S LIST FOR ONE BUILDING

YARD 1—DIMENSION MATERIAL

Checker .... Date .... Time .... Building No. ....

81 Pieces			Mud Sills
81 "			Foundation Posts
2 "	4x 4	16	Posts
1 "	4x 4	14	Posts
12 "	4x 4	13-10¾ (Sq.)	Posts
6 "	4x 4	12	Posts
21 "	4x 4	10-6½ (Sq.)	Posts
10 "	4x 4	9	Posts
4 "	2x12	16 (Notched)	Stair Strings
3 "	2x12	9 (Notched)	Stair Strings
106 "	2x 8	20	Girders
276 "	2x 8	12	Joists
272 "	2x 8	10	Joists
516 "	2x 8	1-10¼ (Sq.)	Bridging
116 "	2x 6	23-8 (F)	Rafters
40 "	2x 6	20	Ledgers and Roofing Purlins
14 "	2x 6	10	Ridge
30 "	2x 6	6	Platforms and Treads
112 Pieces	2x6	2-4¼ (Sq.)	Eaves Blocking
10 "	2x4	24	End Wall Studs
8 "	2x4	20	End Wall Studs
126 "	2x4	18	Studs and Braces
242 "	2x4	16	Soles and Girts
45 "	2x4	14	Bracing
56 "	2x4	12	Bracing, Partition Studs and Wall Studs
43 "	2x4	10	Bracing, Partition Studs and Wall Studs
52 "	2x4	8-11 (Sq.)	Studs First Floor
18 "	2x4	6-4 (B)	Eaves Knee Braces
22 "	2x4	4-6 (D)	Top Braces Center Posts
78 "	2x4	4-4 (A)	Post Braces First Floor
52 "	2x4	3 (C)	Purlin Braces

YARD 1—SPECIAL MILL WORK

Checker .... Date .... Time .... Building No. ....

3 Pieces	⅜x4	5-6	Thresholds
90 "	1x2⅜	6-10	Door Stops
30 "	1x3	6	Casings
6 "	13/16x13/16	6-10	At Exterior Doors
15 "	13/16x6 9/16	5	Risers
19 "	1⅛x11¾	5	Hardwood Treads
1 "	3¾x3¾	6	Newel Post
2 "	3¾x3¾	3-6	Newel Post
10 "	1¾x1¾	3-6	Balusters
1 "	1¾x3¾	16	Dressed Handrail
1 "	1¾x3¾	12	Dressed Handrail
12 "	13/16x9¾	10	Shelves
413 Pieces	13/16x13/16	3	Marked J
1020 "	13/16x1⅝	3	Marked B
83½ "	1¾x2½	6	Marked K
211 "	13/16x2¼	3	Marked F
79 "	13/16x3¼	6	Marked C
88 "	13/16x3	6	Marked D
79 "	13/16x4 9/16	3	Marked E
83½ "	13/16x8¾	6	Marked H
167 "	1¾x2 7/16	6	Marked G
11 Astragals	13/16x1⅜	6-8	
3 Pieces	2x6	5-6	Door Sills

YARD 1—MISCELLANEOUS

Checker .... Date .... Time .... Building No. ....

3 Pieces	Drain Boards
172 Squares	Tarred Felt
72 "	2-Ply Felt Roof
167 Pieces	Sash
4 Pieces	Exterior Glazed Doors
11 "	Plain Doors

YARD 2—BOARDS

Checker .... Date .... Time .... Building No. ....

328 Pieces	1x 3	10	Nailing Strips
32 "	1x 3	12	Gable Strips and Bracing
37 "	1x10	10	Head Casings
7 "	1x10	12	Head Casings
37 "	1x 8	14	End Blocking
50 "	1x 6	10	Roof Ties and Between Rafters
116 "	1x 6	1-9 (E)	Vent Brackets
20 Pieces	1x 6	12	Roof Ties
6 "	1x 6	24	Barge Boards
11200 Sq. Ft.		(Net)	Rough Floor
11200 "		(Net)	Finished Floor
5500 "		(Net)	Drop Siding
7700 "		(Net)	Roof Boarding
4600 "		(Net)	D. & M. Wainscot
236 Pieces	1x5¾	1-5	Baffles

See special schedules for Sheet Metal, Wall Board and Hardware.

Fig. 7. Material List for 200-Man Barrack.

At the height of construction more than one million feet of lumber per day was hauled from the yards to building sites.

HANDLING OF MATERIALS

Sorting. All materials were sorted into sizes and lengths as unloaded except for one inch rough boards, which came in random

Fig. 8. Typical One-Story Buildings. A Regimental Administration Building in the Foreground.

widths and lengths. Checkers made record of all materials received in the yards, also all materials sent out to the building sites.

Checking. At each yard there was kept a list of all materials required to construct each kind or size of building in the cantonment. Each building was identified by regiment, or group, and number. When the head checkers at the yards received orders to send out the materials for a certain building, a checker listed in duplicate the materials as they were loaded on the wagon. The driver was given the two copies upon which had been noted the regiment and building number. When the load of material reached the regiment, or group of buildings to which it was consigned it was met by another material checker who directed the driver to the site of the building indicated on the list of materials, checked the material as it was unloaded, signed one of the lists if correct, and returned it to the driver, who took it back to the yard, where it was placed on file. The duplicate list was kept on file at the office of the building outfit. At any time the head checker could tell just what materials had been sent out to any given building, and just what remained to be sent.

This method of checking the delivery of materials did not work successfully in all cases, because of the human element entering in. The drivers were sometimes ignorant, and the checkers often lazy and careless. In the main, the system worked very satisfactorily.

LUMBER ERECTION

Power Saws. Power saws were used extensively and to good advantage. A few band saws were used, but most of the saws were of the circular variety, mounted on frames and driven by gasoline engines. They could be readily dragged from place to place with four horses, or a truck.

At the beginning of the work it was thought possible that most of the sawing could be done at the yards, and that at the building site there would be little to do except to assemble the pieces and nail them together. In conformity with this idea, cutting lists and drawings were made for one or two of the larger buildings. The cutting lists gave the dimensions of all pieces which were duplicated several times. Also sketches were shown of all pieces not having square cuts. The drawings were erection sketches to be used in the assembling of the pieces.

We were partially disappointed in the working of this scheme. While all materials were ordered S 1 S 1 E (dressed one side and one edge), the materials as received were in all stages of manufacture. Some pieces were undressed, some were dressed on four sides. The thickness of one piece might be 2¼ in. and the next one 1½ in. Therefore, it was of little use to saw pieces at the yards if their lengths depended upon the thicknesses of other pieces. For this reason the plan to cut so many pieces at the yards was abandoned. However, in spite of some of the difficulties encountered, it was possible to do a great deal of sawing at the yards with power saws. All rafters, knee braces, bridging, blocking, stair stringers, and most of the studs were cut in this way.

Power saws were also stationed near the buildings under construction and were kept busy ripping and sawing lumber, especially on parts that were duplicated.

There were two general methods used for handling the workmen on building erection. One method was to assign a carpenter foreman with 25 to 40 carpenters to a building, after the foundation posts had been set, and have them carry the building through to completion except for the window trim and the roofing. The other method was to have one gang to set the foundation posts; another to build the frame; a third to lay floors, and put on siding and sheathing; a fourth to do the finishing; and a fifth to do the roofing.

The first method seemed to be the more satisfactory to the foremen and workmen, but the second was more satisfactory to the general foreman and the field superintendent. In the first method the foreman and men must know how to construct the entire building. Many of the foremen could not, or would not, follow the plans closely, hence it was necessary to watch the work closely and give in-

structions constantly. In the second method there were not so many different operations to be performed, and the same operations were repeated many times.

PROGRESS REPORTS

A progress department was established by the contractors to inform the government of the progress of erection, and to have a

TWO STORY BUILDINGS

DESCRIPTION OF BUILDINGS	BARRACKS					MED. DEPT.		HDQRS & SUPPLY	
	43x140	43x120	43x100	43x86	43x69	20x98	20x119	43x98	43x130
Mud Sills-Posts & Bracing	1200	700	1100	1000			1000	1000	1200
1st Fl. Girders & Sills	1900	1600	1300	1400			900	1400	1700
1st Fl. Joists & Bridging	5200	4600	4000	3500			2300	3800	5200
1st. Fl. Underflooring	6000	5200	4300	3700			2300	4400	6100
Total	14300	12100	10700	9600			6500	10600	14200
Outside Studs, Ledgers, Plates	2500	3200	2100	1800			2400	2200	4300
1st. Story Posts, Girders, Braces	1800	1700	1600	1500			900	1000	2200
2nd Fl. Joists & Bridging	4500	3900	3200	2500			2300	2700	3600
2nd Fl. Underfloor	5200	4300	3400	2600			2400	2600	4000
Outside Sheathing	5900	4900	4300	4000			4100	4500	5400
Total	19900	18000	14600	12400			12100	23000	19500
2nd Story Posts & Purlins	1000	1300	1300	400			300	1000	600
Rafters, Ties, Braces.	3600	2700	2600	2200			1800	2300	3400
Roof Sheathing	8200	7300	6000	4900			4500	5700	7300
1st Fl. Finished Flooring	6000	5200	4300	3700			2400	4300	6100
2nd Fl. Finished Flooring	5200	4300	3400	2600			2400	2700	4000
Total	24000	20800	17600	13800			11400	16000	21400
Wall Struts	3000	1800	1500	1200			1300	2600	3400
Wainscoting on Outside Walls.	3100	2300	2000	1700			1900	2000	2300
Inside Sheathing & Partitions	2600	2300	2000	2700			4000	3600	4700
Window & Door Trim	2500	3400	2400	2800			2800	2800	3000
Tables, Miscel. Details	2600	1800	1700	800			1000	2400	2000
Total									
Total in Building	72000	62500	52500	45000			41000	53000	70500

ONE STORY BUILDINGS

DESCRIPTION OF BUILDINGS	BARRACKS					LARGE OFFICERS QUARTERS						
	20x35	20x49	20x56	20x70	20x108-6	20x70	20x80-6	20x91	20x101-6	20x112	20x122-6	20x133
Mud Sills, Posts, Bracing		500			900		700	800		1000		1100
1st Fl. Sills & Girders		300			700		500	600		600		800
Joists, Bridging, Blocking		600			1200		1000	1000		1300		1600
Underflooring		1000			2200		1600	1800		2300		2200
Total		2400			5000		3800	4200		5200		6200
Outside Studs		300			1000		900	900		1000		1700
Posts, Ties, Plates		200			300		200	300		300		300
Rafters		700			1500		1200	1200		1500		1500
Sheathing		1600			2800		1800	2100		800		3700
Finished Flooring		1000			2200		1600	1800		2300		2600
Roof Sheathing		1600			3500		2600	3000		3500		4300
Total		5400			11300		8300	9300		9400		14100
Wall Struts		100			200		600	1000		700		500
Wainscoting-Outside Walls		600			1000		800	800		1000		1200
Inside Sheathing & Partitions		1000			1000		3500	3700		5300		5200
Window & Door Trim		300			1000		500	500		900		800
Total in Building		10000			19500		17500	19500		22500		28000

Fig. 9. Schedules of Lumber in Typical Buildings.

record for their own information. Men from this department visited every unit of construction and estimated the amount of work done or the number of feet of lumber erected each day. The data thus secured was compiled each evening and made available to the administrative officers.

The method of making the estimates of quantities was, of necessity, one which could be operated easily and quickly. Work was in progress at all parts of the cantonment and the progress men could not stop long at any one place. For building erection, tables were made on which were given the number of feet of lumber required to complete each stage. The stage of erection of any

building was noted by the progress man and by means of the table it was a simple matter to estimate the number of feet erected.

The progress reports were invaluable to the materials and erection departments. The materials department thus secured informa-

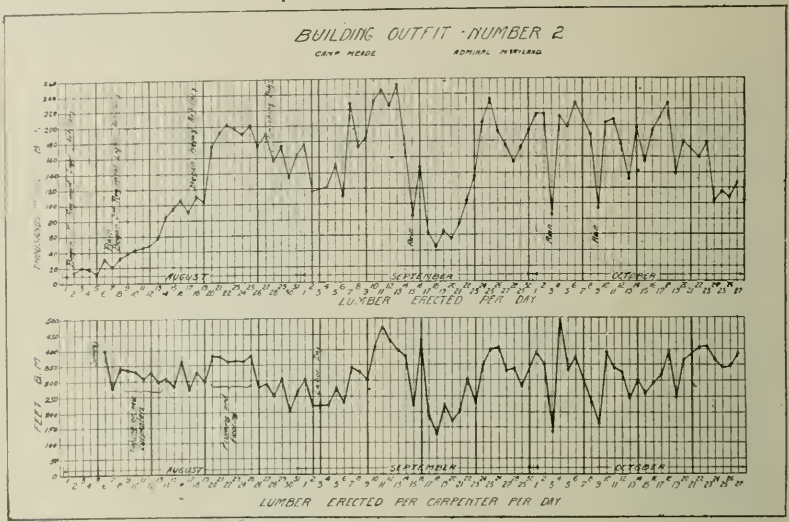

Fig. 10. Charts Showing Amounts of Lumber Erected Daily, and by Carpenters Daily.

tion with regard to the amount of material used by each building outfit and could govern the next day's hauling accordingly. The erection outfits could judge as to the efficiency of their departments and compare different methods of operation.

DEVICES FOR SHOWING PROGRESS AND EFFICIENCY IN THE BUILDING OUTFIT

As a means of stirring up some rivalry between the different building outfits, charts were made as shown in the diagram, Fig. 10. Each morning the data from the day previous was plotted. This diagram gives the amount of lumber erected each day by Building Outfit No. 2. This building outfit was just getting under way when the chart was started. It may be noted that shortly after the beginning of work on a new group of buildings the number of feet erected increased rapidly. Rain caused a drop in the curve on several occasions. The drops in the curve on the second to sixth and eighteenth to twentieth of September are due to the fact that many men were employed on inside finishing, such as trimming windows, hanging doors, building stairs, etc., which precludes the possibility of erecting a large footage. These dates also mark the completion of a group of buildings. The lower diagram illustrates a method used to give some idea as to the efficiency of the workmen. Numerous reasons may be given for the irregularity of the curve. Men en-

gaged on framing or flooring could erect a large footage, while on finishing, the footage would be small. Rainfall interfered with the progress as may be seen by both diagrams; but the day following a rain was usually marked by a distinct rise in the amount of lumber erected per carpenter. While new foremen and large numbers of carpenters were being added to the force the curve indicates a gradual decrease in efficiency. This is shown by a comparison of the two curves on August 8 to 15. Labor Day did not affect the outfit on the days preceding or following. Sunday, with only three exceptions, is marked by a falling off in the amount of lumber erected per carpenter; and one of the Sundays showing an increase followed a rainy Saturday. This appears to indicate that workmen do not labor as energetically on Sundays as on other days. Another reason which might account for the falling off in lumber erected on Sundays is that laborers only received time and a half on Sundays, while carpenters received double time. The result was a shortage of laborers and the carpenters were required to carry their own lumber and materials. It appears that 60 cents per hour for laborers on Sunday would have been a more economic procedure than to employ carpenters at $1.25 per hour to do laborers' work.

A record was also kept of the lumber erected by the carpenters under the direction of each general foreman, from which conclusions could be drawn as to the efficiency of the foreman.

The information required to plot the diagrams was easily obtained from the progress department, required little time for posting, and the results obtained made it well worth while.

SOME DATA ON ERECTION

The following data was furnished by R. M. Regan, Superintendent of Building Outfit No. 2:

The construction of the buildings for training battalions designated as Regiment AA was determined upon on Friday, September 21. Regiment AA consists of:

- 32 two-story barracks, 30 by 60 feet;
- 8 one-story mess halls, 20 by 147 feet;
- 4 one-story officers' quarters, 20 by 133 feet;
- 1 two-story medical building, 20 by 119 feet;
- 2 one-story store houses, 20 by 98 feet;
- 2 stables, 29 by 40 feet;
- 2 wagon sheds, 29 by 18 feet;

a total of 51 buildings.

The material required was:

- 2,108 posts;
- 1,490,000 feet of yellow pine lumber.
- 321,000 square feet of building paper;
- 152,000 square feet of roofing;
- 3,838 window sash;
- 304 doors;
- 136,400 square feet of wall board;

782 square feet of brick hearth;
30,514 pounds of nails.
2,184 lineal feet of mess tables with seats were constructed.
1,660 lineal feet of fire ladders were erected.

The hauling of posts, lumber, and other materials was begun on Saturday, September 22. Actual construction began on Sunday, September 23. A 10-hour work-day was observed. Lumber erection was completed and the buildings were finished at 6 p. m., October 2. Ten days, or 100 hours, was required to complete the 51 buildings of this regiment. Fifteen thousand feet of lumber was erected each working hour, and a building was completed every two hours.

Fig. 11. The 200-Man Barrack. Typical of All Two-Story Buildings.

The number of carpenter and labor hours required to complete each stage of construction of a 200-man barrack is as follows:

			Lumber required ft. b. m.
Foundation Posts	Carpenters	20 hrs.	
	Laborers	60 hrs.	1,000
Framing Complete	Carpenters	375 hrs.	
	Laborers	72 hrs.	20,700
Sub-Floors and Roof	Carpenters	390 hrs.	
	Laborers	50 hrs.	19,400
Trim—			
Finished Floors			
Wainscoting			
Inside and Outside Stairs			

Doors	Carpenters	530 hrs.	
Sash	Laborers	85 hrs.	25,000
Partitions			
Tables			
Counters			
Screening			
Outside Sheathing	Carpenters	450 hrs.	
	Laborers	40 hrs.	5,900
Wall Board	Carpenters	320 hrs.	
	Laborers	40 hrs.	
Roofing Felt	Carpenters	70 hrs.	
	Laborers	20 hrs.	
Undersheathing and Ladders	Carpenters	60 hrs.	2,000
	Laborers	15 hrs.	
Total			74,000

Total carpenter hours on lumber erection, 1,825.
Total labor hours on lumber erection, 322.
Lumber erected per carpenter per day, 407 ft. b. m.

Carpenters received 62½ cents per hour, and laborers 30 cents per hour.

THE WORKMEN

It would not be proper to discuss the building erection of army cantonments without saying a word about the workmen. All classes were present and most of them claimed to be carpenters. If a collection were made of all obsolete, rusted out and worn out tools brought to the camp site, the collector would have a good start in the junk business.

Most of the men belonged to the class called "floaters." Some of them were good mechanics; most of them were very ordinary workmen. If a man showed even ordinary ability and had any energy whatsoever, he was retained. The work was to be done and if good workmen could not be secured the poor must be endured. The word "economy" does not appear in the war dictionary.

The following incidents are related to indicate the character and skill of the workmen: A carpenter (?) was seen crawling around on his hands and knees on the second floor joists. He was afraid to stand for fear he would fall.

A carpenter (?) distributed wainscoting along the outside of the building and thought it was drop siding.

Foreman Deggs said to a new carpenter as he came on the job, "Are you a mechanic?" "No," was the reply, "I am an Italian."

Foreman Price told a new carpenter to get out on the scaffold and help put on siding. The carpenter asked, "What tools will I need?" Price's reply was, "I don't know what tools *you* need, but *I* generally use a pick and shovel."

A laborer was discharged because his services were of no value. He went to another part of the camp and secured employment as a

carpenter. In a few days he was advanced to the position of sub-foreman. He evidently had missed his calling in the first instance.

Attention was attracted to a certain carpenter foreman because he was advancing laborers to the rank of carpenter. Upon investigation it was discovered that he was getting a "bonus" of five dollars per week from each man thus advanced.

The foreman of a gang of about 20 carpenters refused to have his gang divided. His method of protest was to sit down and do nothing. He and those of his men who refused to work were promptly discharged.

Fig. 12. Workmen Waiting Their Turn at the Mess Hall.

Men who began work as carpenters often were reduced to laborers.

Labor conditions on such work surely are not what might be desired, but the work must be done, and with the class of labor available.

GENERAL DATA

The contract for the construction of Camp Meade was let on Saturday, June 23. The writer arrived in Washington and began his work with the organization on the evening of June 26. There were two men then at work; one, the future assistant manager, the other in charge of the making of bills of material and plans. In four days the office force had grown to about 20 men and was transferred to Baltimore.

The organization began taking definite form about this time, and within a few days had practically reached the form maintained throughout the construction period.

On July 11, the materials department moved to the camp site and took possession of the one permanent building then under roof. It was an officers' quarters building 20 by 112 ft. and one story high.

On September 1, 12 million feet of lumber had been erected, many buildings were complete in every detail, and were ready to receive their quota of the new national army. The working force had increased to 8,000 men.

The latest information is to the effect that 42 million feet of lumber will be used in the construction of this cantonment.

The contractors were Smith, Hauser and MacIsaac, Inc., of New York. Lazarus White was manager, and R. V. Engstrom, assistant manager.

HEATING, COOKING AND LAUNDRY EQUIPMENT OF THE NATIONAL ARMY CANTONMENTS

By Prof. A. C. Willard*

Presented Dec. 3, 1917

INTRODUCTORY STATEMENT

The work of the Cantonment Division, Office of the Quartermaster General, U. S. Army, as carried on in Washington during the summer of 1917 was under the general charge of Col. (now General) I. W. Littell, (U. S. A.) and the engineering details of the heating and cooking equipment were under the immediate supervision of Maj. F. M. Gunby and Capt. L. H. Tripp of the Reserve Corps.

The laundry equipment erected for the government, and private laundries were also under the direct supervision of Maj. Gunby and Mr. E. V. Dunstan, Advisory Architect, O. Q. M. G.

The writer was connected with this work from June 17 to August 7, 1917, in the general capacity of consulting engineer.

It should be made very plain at the outset that unlimited funds were not available for use in equipping these cantonments, although this idea seems to be more or less prevalent The time required for completion was an equally vital consideration. As a result, at almost every step in the progress of specifying and designing this equipment it was necessary to balance considerations of efficiency of operation, questions of maintenance, durability or probable life of apparatus in service, against first cost. The result was often not all that we could wish, as any practicing engineer can readily understand.

The following discussion applies to the sixteen cantonments (Table 1) for the new national army which are located at:

Table 1

Name of Camp	Location of Camp
Devens	Ayer, Mass.
Upton	Yaphank, L. I.
Dix	Wrightstown, N. J.
Meade	Annapolis, Md.
Lee	Petersburg, Va.
Jackson	Columbia, S. C.
Gordon	Atlanta, Ga.
Sherman	Chillicothe, Ohio
Zachary Taylor	Louisville, Ky.
Custer	Battle Creek, Mich.
Grant	Rockford, Ill.
Pike	Little Rock, Ark.
Dodge	Des Moines, Iowa

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Funston	Fort Riley, Kansas
Travis	Fort Sam Houston, Tex.
Lewis	American Lake, Wash.

Each cantonment accommodates a division of at least 36,000 men, and most of them also provide for special trains which will increase the garrisons to above 40,000 men.

HEATING EQUIPMENT

Two general methods of heating these cantonments have been employed. The first method makes use of room heaters and cannon

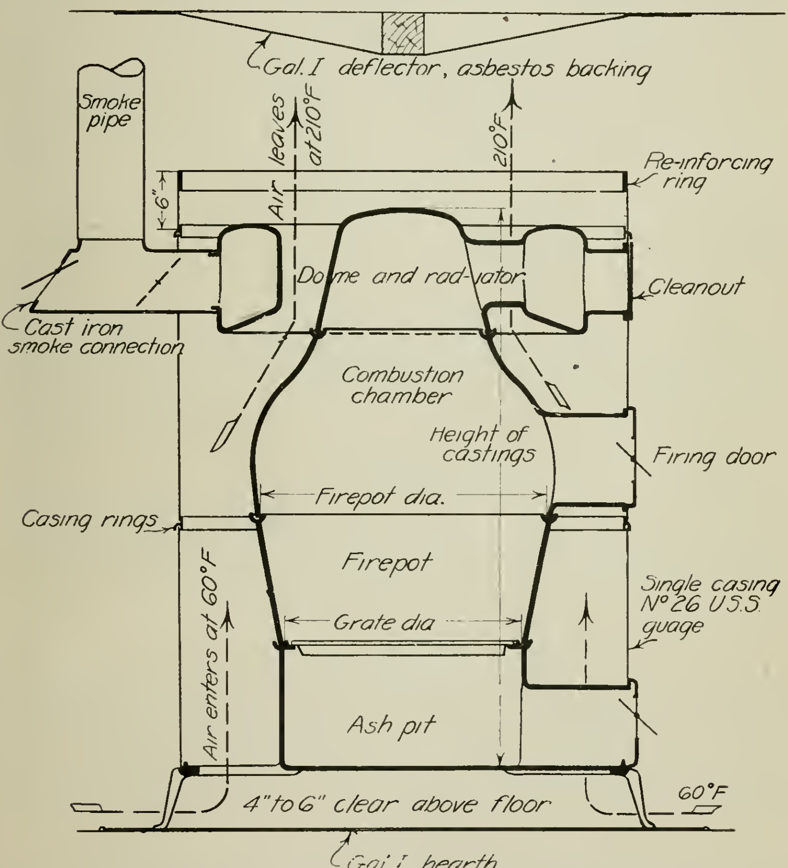

Fig. 1. Diagrammatic Section of Cantonment Room Heater. Cast Iron Sectional Type.

stoves placed directly in the rooms to be warmed. The second method provides for central steam heating systems with direct radiation operating under reduced steam pressure. Certain small one-story buildings, with numerous rooms, such as officers' quarters,

have isolated low-pressure gravity-circulating steam heating systems. This latter arrangement is provided at all 16 cantonments for buildings of this type. With the funds available and with the time limitation imposed, it was found impossible to provide central plants at hardly a third of the camps, and hence room heaters and stoves have been very generally used.

ROOM HEATERS

Room heaters, as now installed, range in size from 14 in. to 28 in., or slightly larger, in *grate* diameter. These heaters are all of cast-iron sectional construction, including the following sections: (1) a one-piece ash pit, (2) a one or two-piece fire pot, (3) a one-piece combustion chamber, and (4) a circular radiator, preferably cast in one piece. These castings are enclosed by a circular No. 26 U. S. S. Gauge galvanized iron casing, and both castings and casings are elevated from 4 to 6 in. above the floor, to permit free entrance of air at the floor line to the space between casing and castings. The casings extend well above the top of the castings and are in general not less than twice the grate diameter. See Fig. 1 and typical specifications which follow.

SPECIFICATION PROPOSAL FOR ROOM HEATERS

For one division there will be required approximately 1,200 room heaters and small furnaces classed as room heaters, ranging in size from 16-inch grate diameter to 26-inch grate diameter, *measured at the grate level.*

Bidders must furnish with their proposals all information called for on Proposal Data Sheet, herewith.

The attention of each bidder is especially invited to the fact that, in order to entitle his bid to consideration, the Proposal Data Sheet accompanying same must show the Grate Diameter as well as the top diameter of fire pot of each size of heater bid on.

GENERAL SPECIFICATIONS

Room heaters and furnaces classed as room heaters must be constructed of cast iron with single casing of galvanized iron supported by heavy casing rings. Alternate bids on black iron casings finished with one coat of quick drying black japan will be considered, provided deduction to be made if black iron casing is substituted, is stated in the bid.

HEATER

Heater shall consist of the following cast iron sections:

1. Base with casing ring.
2. Grate and ash pit section.
3. Fire pot, preferably in two sections.
4. Combustion chamber.
5. Circular radiator placed above and around combustion chamber, with smoke opening in rear. One piece radiators are pre-

ferred, and all radiators must be provided with at least one cleanout in addition to smoke opening.

GRATES

Heater must be equipped with heavy triangular rocking grates or with heavy flat draw-center shaking grates. All grates must be easily replaceable for repairs.

CASINGS

All heaters and casings must be supported on heavy legs with from 4 to 6 in. air space between casing and floor. Casing diameters must be not less than twice the grate diameters, in all cases. Top of casing must project well above all furnace castings. Casings must be of No. 26 U. S. S. gauge galvanized iron.

There must be at least two casing rings in addition to the base ring so that casings will be fully reinforced.

ACCESSORIES

Each heater must be provided with cross damper to fit smoke pipe and must have a separate cast-iron smoke connection with check damper in same. This smoke connection must be so arranged that cross damper can be placed between heater and check damper.

A full set of firing tools and equipment, including shovel, to fit fire door, two shaker handles, poker and coal can of 26 gallons capacity and ash pan. Bucket and pan must have suitable handles or bail for handling. (Ash pan was afterwards omitted.)

PROPOSAL DATA

(To be furnished for each size of heater bid on.)

1. Number of heaters bidder can supply, f. o. b. factory (Sept. 1 and 15, 1917).*

2. Price, each, f. o. b. factory (based on carload lots).

2A. Deduction from above price if black-iron casing is furnished.

3. Grate diameter (at grate line), inches.

4. Fire pot diameter (top of fire pot), inches.

5. Number of sections in fire pot.

6. Casing diameter, inches.

7. Gauge of metal in casing, U. S. S.

8. Weight of heater and casing set up, pounds.

9. Type of grate and number of bars in same.

10. Diameter of smoke pipe or collar, inches.

11. Height of bottom of casing above floor, inches.

12. Height of top of casing above floor, inches.

13. State whether heater has straight or angle type of smoke connection for check damper.

Over fifty manufacturers bid on this equipment and promised to deliver about 23,600 room heaters by September 1 and about

*(Date to be inserted by Purchasing Department.)

19,000 more by September 15. By August 1, 1917, awards had been made to some 30 manufacturers for a little over 12,000 cast-iron room heaters. Unfortunately, most of the heaters bid upon were of the smaller sizes, whereas practically all the large two-story barracks of 200 men capacity each required heaters of 24 in. grate diameter or larger. A standard cantonment required approximately 1,200 of these units, where no central steam plant was installed. This, of course, does not include the cannon stoves for lavatories, and small N. C. O. rooms and offices, of which about an equal number were required.

RATING OF ROOM HEATERS

The question of rating these room heaters became a matter of prime importance. In the absence of actual service test data for similar equipment, installed in such buildings as the government proposed to erect, the schedule in Table 2 of assumptions and capacities in B. t. u. per hr. was used as a basis for determining grate

Smoke Pipe Dia. Ins.	Top Firepot Dia. Ins.	Actual Grate Dia. Ins.	Grate Area Sq. ft.	Lb. Coal per Hr. per Sq. ft. of Grate Area	Heat Value of Coal Btu./Lb.	Percent Efficiency	Btu. per Hr. Supplied by Stove or Heater
			Cannon Stoves				
6	10	7	0.268	4.5	12 000	50	8 000
6	12	9	0.443	5	"	50	14 000
7	14	10	0.545	5	"	50	17 000
7	16	12	0.785	5.5	"	60	32 000
7	18	14	1.070	5.5	"	60	43 000
8	20	16	1.400	6	"	60	61 000
			Room Heaters				
7	18	14	1.07	5.5	12 000	60	43 000
8	20	16	1.40	6	"	"	61 000
8	22	18	1.77	6	"	"	77 000
9	24	20	2.18	6	"	"	95 000
9	26	22	2.64	6.5	"	"	124 000
10	28	24	3.14	6.5	"	"	148 000
10	30	26	3.70	7	"	"	187 000
10	32	28	4.28	7	"	"	215 000

Table 2. Ratings and Capacities of Stoves and Room Heaters.

sizes of the heaters required in each case. This schedule was developed in consultation with Capt. Tripp, together with data furnished by a special test at the University of Illinois and by the National Warm Air Heating and Ventilating Association on equipment of this sort. The ratings are believed to be conservative, as reference to the test data given later will show.

With the schedule in Table 3 as a basis it was only necessary to calculate the probable B. t. u. loss (in coldest weather) from any barrack, officers' quarters, lavatory, hospital or other building in order to select (as in the case of steam radiation) the proper size of unit. The grate area was used as the most characteristic dimen-

sion in making the selection of unit. (See example following under "Heat Loss Calculations for a Barrack.")

The original scheme of heating (Fig. 2) provided for a double drum unit which was abandoned largely as a result of space limitations imposed by the change from double deck to single cots. As one of the engineering societies has already published plans and descriptive matter of this original scheme as though it had been installed, the writer desires to correct this idea, and also submit certain test data showing the performance of such a heater.

TESTS ON A DOUBLE DRUM BARRACK ROOM-HEATER AT THE UNIVERSITY OF ILLINOIS

(The type originally proposed for cantonment buildings.)

Reference has already been made to some special tests on barrack room-heaters and also to the fact that the original scheme of heating had to be modified. These tests were conducted at the University of Illinois early in July by Mr. A. P. Kratz on equipment furnished by the Culter and Proctor Stove Co., of Peoria, Illinois, and the results transmitted to the Cantonment Division.

TABLE 3

SMOKE PIPE RATINGS

SMOKE PIPES CANNON STOVES

Smoke Pipes Diam. in inches.	Grates. Diam in inches.	Firepot (top) Diam. in inches.
6	7	10
6	9	12
7	10	14
7	12	16
7	14	18
8	16	20

SMOKE PIPES ROOM HEATERS

Smoke Pipes Diam. in inches.	Grates. Diam in inches.	Firepot (top) Diam. in inches.
7	14	18
8	16	20
8	18	22
9	20	24
9	22	26
10	24	28
10	26	30
10	28	32

The equipment was arranged as shown in Fig. 2, and the tests were of eight hours duration, using a run of mine coal from Sharon mine at Georgetown, Illinois, of the following composition:

Approximate Analysis of Coal (as Fired.)

Fixed Carbon .... 42.28 per cent
Volatile Matter .... 32.72 per cent

Moisture	13.05 per cent
Ash	11.94 per cent
	100.00 per cent
Sulphur separately determined	1.89 per cent
Calorific Value per lb. (as received)	10,589 B. t. u.

The results of the tests show:

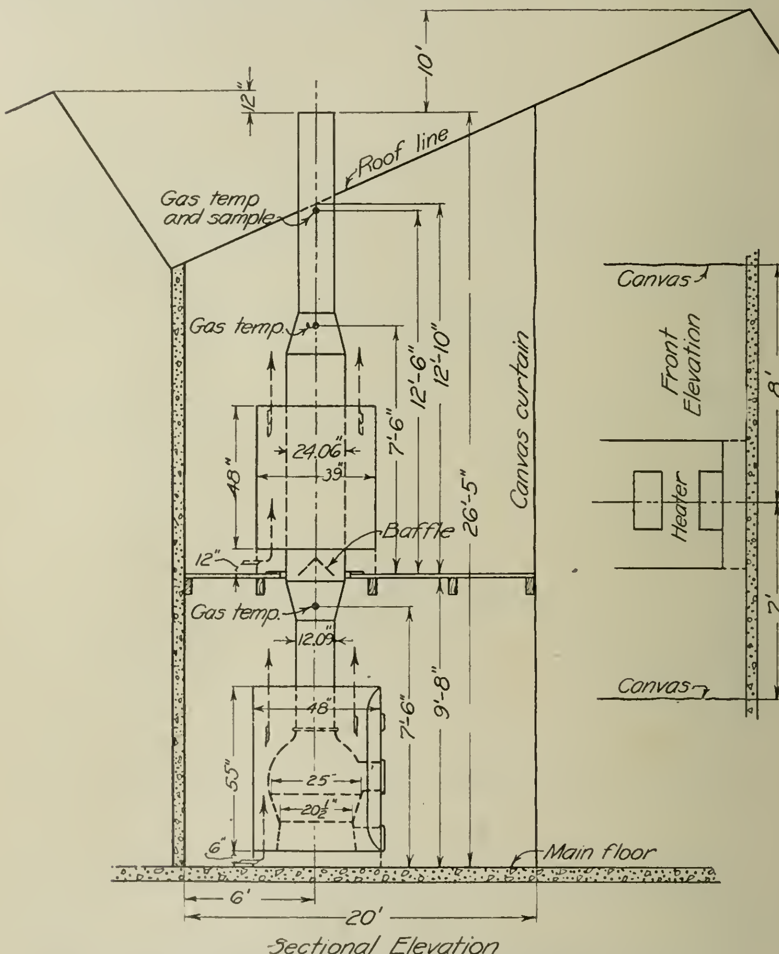

Fig. 2. Double Drum Cantonment Barrack Heater, as Tested at the University of Illinois.

(1) That a draft of 0.15 in. water could be obtained with a 12 lb. combustion rate on a grate 20½ in. diameter and firepot 25 in. diameter at top.

(2) The heat was unequally distributed, the lower floor receiving by far the larger part.

(a) Air entered lower casing at 93.6 deg. and left at 254.4 deg. or a rise of 160.8 deg. F., so that total heat taken up by air on first floor was 3,975 B. t. u. per hr. per lb. coal burned.

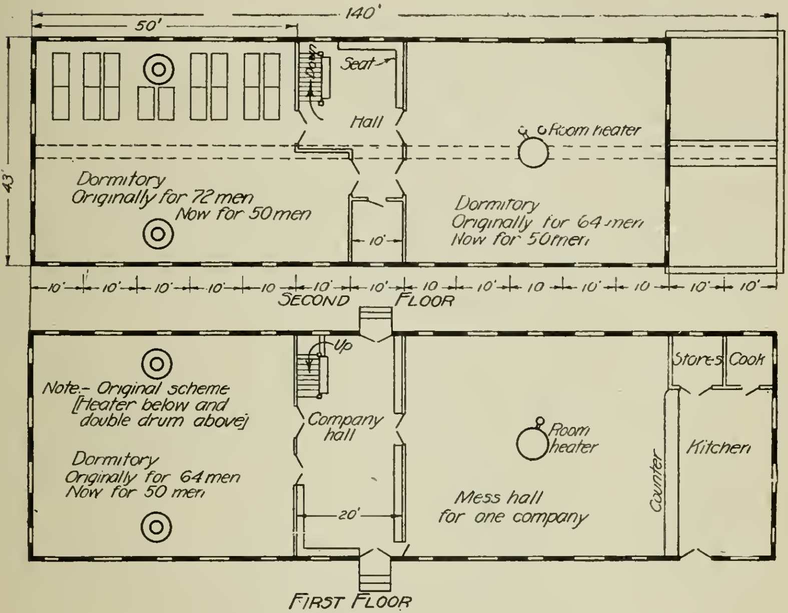

Fig. 3. Company Barrack. Original Capacity, 200 Men. Now Used for 150 Men.

(b) Air entered upper casing at 123.2 deg. and left at 133.5 deg. or a rise of 10.3 deg. F., so that total heat taken up by air on second floor was 222 B. t. u., per hr. per lb. of coal burned.

(c) The heat given off by radiation on the two floors was also much greater for the first than for the second floor. Total radiation both floors was 4,721 B. t. u. per lb. coal burned.

(3) The flue gas temperatures were as follows:

(a) At a point 7 ft. 6 in. above 1st floor = 995 deg. F.

(b) At a point 7 ft. 6 in. above 2nd floor = 408 deg. F.

(c) At a point at roof line = 338 deg. F.

(d) Gas analysis (Orsat).

$CO_2 = 11.22$ per cent.

$O_2 = 5.63$

$CO = 0.00$

$N = 83.15$

(4) Heat loss in flue gases above roof line, including moisture was 1,452 B. t. u. per 1 lb. of coal burned, and heat loss to ash pit per 1 lb. coal burned was 219 B. t. u. or a total of 1,671 B. t. u.

$$(5)\ \text{Efficiency} = \frac{\text{heat delivered to rooms per 1 lb. coal burned}}{\text{heat value of coal burned per 1 lb.}}$$

$$= \frac{8,918}{10,589} \times 100 = 84 \text{ per cent.}$$

(6) This equipment operated with very little smoke, except for a few minutes at time of firing. Soot collected in the upper drum.

(7) No part of furnace or flue became red hot even with a combustion rate between 11 and 12 pounds per sq. ft. of grate.

(8) Fire required little attention, and test was run with dampers nearly closed, and with almost no change in adjustment.

HEAT LOSS CALCULATIONS FOR THE LARGE 200-MAN BARRACK

In order to arrive at size of room heaters, cannon stoves or direct radiation it was necessary, of course, to first compute the probable heat loss from the various buildings, and the large company barrack is taken as an illustration.

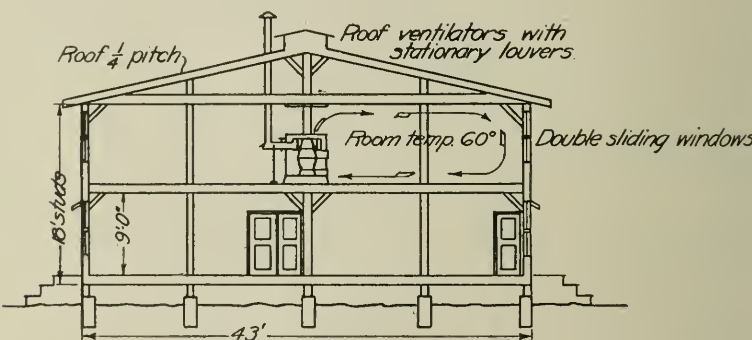

Fig. 4. Elevation Section of Company Barrack. Two Room Heater on Each Floor.

This is a two-story frame structure, 43 ft. by 140 ft., of which about 20 ft. at one end is only one story high, serving as a kitchen. In the original plans (Fig. 3) there was a transverse hall 20 ft. wide running across the building on the 1st and 2nd floors, leaving four rooms practically 43 ft. by 50 ft. Three of these were used as dormitories and the fourth, which was on the first floor and next to the kitchen wing, was intended for a mess hall. The story height is 9 ft. 6 in. for first floor (Fig. 4) and about the same at the eaves line on the second floor, but considerably more at the center, owing to the pitch of the roof. The windows are of single sash approximately 3 ft. by 3 ft., arranged in double tier, each sash sliding to the side and giving a full opening.

Heat loss first floor dormitory (capacity, 64 men).—The total "glass" area in the first floor dormitory, with 6 windows on the end and 7 on each side, is:

(6 plus 2 x 7) x 3 x 3 x 2 = 360 sq. ft., or 56 sq. ft. per man.

The total wall area is:

143 by 9.5 ft. = 1,358.5 sq. ft., and the net area, less glass = 1,000 sq. ft.

The total floor area is:

43 by 50 ft. = 2,150 sq. ft., or 33.6 sq. ft. per man.

The volume is 43 by 50 by 9.5 = 20,425 cu. ft., or 320 cu. ft. per man.

The crackage, assumed at $\frac{1}{16}$ in. in width around the sash, is 21 ft. per double sash or $21 \times (6 + 2 \times 7) = 420$ lin. ft. Basing total infiltration of air on ½ of this we have $½ \times 420 = 210$ lineal ft. as a basis.

The heat loss coefficients per sq. ft. are: (1) for single glass = 1.13 B. t. u.; (2) for outside wall (⅞ in. wood, single ply felt, and ¼ in. wall board) = 0.25 B. t. u.; (3) for wood floor 1¾ in. = 0.37 B. t. u.; and (4) per ft. of crack $\frac{1}{16}$ in. wide = 2.4 B. t. u. These coefficients are for 1 deg. F. difference in temperature between the inside and outside air temperatures.

For camps with a minimum outside temperature of 0 deg. F. and with the interior at 60 deg. F. the heat loss from this dormitory is:

(1) Glass transmission loss = 1.13 x 60 x 360 = 24,400 B. t. u.

(2) Wall transmission loss = 0.25 x 60 x 1,000 = 15,000 B. t. u.

(3) Floor transmission loss (space below floor assumed 10 deg. above outside air) = 0.37 x 50 x 2,150 = 39,700 B. t. u.

(4) Infiltration loss at ½ total crack = 2.4 x 60 x 210 = 30,200 B. t. u. (This provides for 24,150 cu. ft. per hr. in leakage or 1¼ air changes.)

Total B. t. u. loss per hr. dormitory closed = 109,300.

For each additional air change which takes place the additional heat loss is 21,500 x 0.087 x 0.24 x 50 = 22,450 B. t. u. per hr. The total heat supplied by occupants is more than sufficient to offset one air change as here shown, since 64 x 400 = 25,600 B. t. u. per hr.

It is, therefore, evident that for this dormitory at a camp with a minimum temperature of 0 deg. F. a room-heater with 22 in. diameter grate is required. (See Table 2.) For a 20 deg. F. camp the heat loss is caluculated at (80/60) x 109,300 or 146,132 B. t. u. per hr. for this same dormitory, and a 24-in. diameter grate is required.

Special attention is directed to the fact that these room-heaters have a large reserve capacity, as conservative combustion rates and efficiencies were made the basis of rating. (See Table 2.) With the tests at University of Illinois as a basis, each heater can readily be forced to a 50 per cent overload, which, in the case worked out above, would allow an additional heating capacity of 62,000 B. t. u. per hr., or the equivalent of about 3 air changes at a 0 deg. F. camp, making a total of 5 air changes per hour possible.

The heat loss from the large second floor dormitory was found, in a similar manner, to be about 140,000 B. t. u. with 1.25 air changes per hour, the increase being largely due to the fact that the roof transmission loss is much greater than the first floor loss. In this case for a zero degree cantonment at 24-in. diameter grate is re-

quired and for —20 deg. localities, since the heat loss is (80/60)x 140,000 = 187,000 B. t. u. per hr. use a 26-in. diameter grate.

CENTRAL STEAM HEATING SYSTEMS

It was at first intended that about one-half of the cantonments, those in northern localities at least, would have central steam heating plants, but the greater installation cost of this equipment, together with the time required for erection, as compared with room heaters, made it necessary to reduce this number to six of the northern or coldest camps and later to four, as follows: Ayer, Mass.; Battle Creek, Mich.; Des Moines, Iowa; Rockford, Ill.; Riley, Kan., and Wrightstown, N. J. In fact, as late as the middle of July so much uncertainty existed as to how far the available funds would go in the time available in providing this part of the equipment, that a unit system of central plants was decided upon, each plant heating a regimental group of buildings. In this way a partial change from central steam systems to room heaters could be made without remodelling the general layout.

Heat losses were calculated on the B. t. u. basis, as already indicated, for room heaters in the case of the 200-man barrack, and radiation selected on the basis of 5-lb. steam pressure within the building to maintain this reduced pressure. The steel boilers are operated and the steam transmitted at much higher pressures up to 60 or 80 lb. gauge, in order to make use of much smaller distributing mains than would be possible using low pressure steam. The cast-iron column radiation installed has a heat transmission value of from 275 to 300 B. t. u. per sq. ft. per hour.

Brick-set horizontal return-tubular boilers of about 150 horsepower each were selected for these plants, and designed for 125 lb. steam working pressure. Proposals were also invited for large cast-iron boilers, which, of course, must be operated at much lower pressures, as it was found that deliveries and prices on steel equipment would make it impossible to use them in all cases. Approximately 265 steel boilers of the horizontal return-tubular type were required.

Practically no provision was made in these central heating systems to return the water of condensation to the boilers, so that a very simple system of main piping was rendered possible. Principal distributing lines were generally carried underground, but in many cases, depending on grouping of buildings and character and use of intervening ground, the mains were run above ground. It is the intention to place as many of the mains below grade as funds will permit, and it is probable that this will be done later with mains now above grade. These aerial mains have a 1 in. air cell covering, over which is placed 1 in. of hair felt and then an outer jacket of waterproof building paper.

A typical regimental layout is shown in Fig. 4-A. The central plants supply over 3,000,000 sq. ft. of radiation. In general each building is controlled by a single valve, so that no valves are used on the individual radiators except in officers' quarters or small rooms.

ROOM-HEATERS AT STEAM-HEATED CANTONMENTS

It was found advisable to heat many isolated buildings even at the so-called steam-heated posts with room-heaters or cannon stoves.

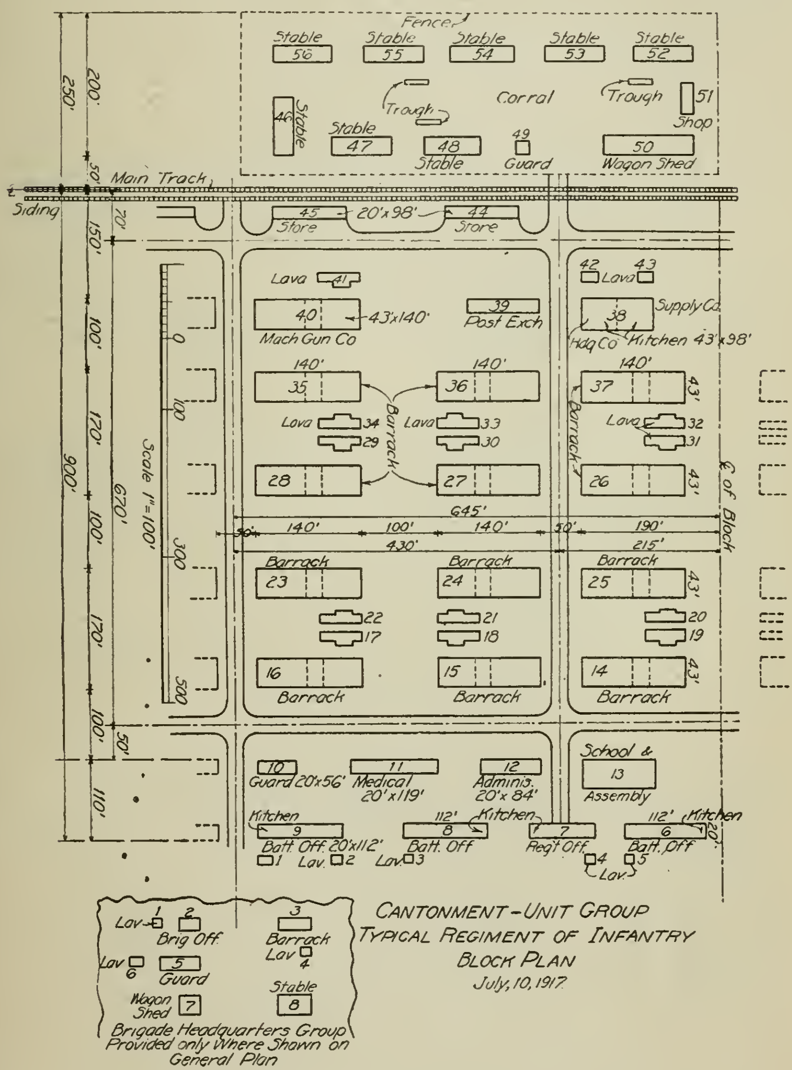

Fig. 4a. A Typical Regimental Layout.

This occurred most commonly in the case of special sanitary trains and other small units. As a consequence room-heaters are found at all cantonments.

ISOLATED STEAM HEATING PLANTS

To avoid the use of a very great number of cannon stoves in buildings used as officers' quarters, and not within reasonable range of a central plant, small isolated steam-heating plants were also used at centrally heated posts. These plants are used not only at the cen-

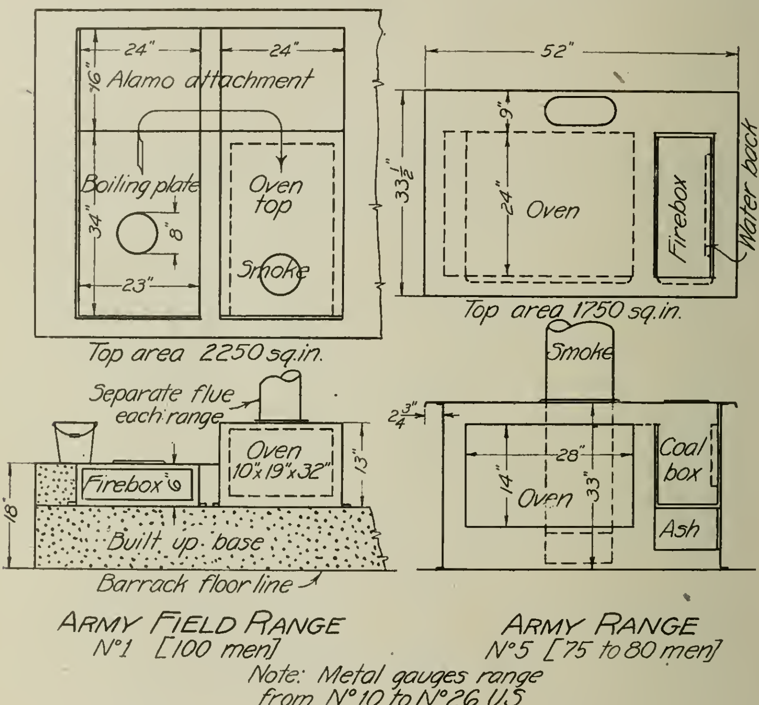

Fig. 5 Fig. 6.

RATING AND CAPACITY SCHEDULE—STEEL RANGES

Capacity	20 men	40 men	60 men	100 men
Top Dimensions	28"x34"	30"x42"	32"x48"	34"x52"
Top Area	950	1260	1560	1760
Top Factor	45	30	25	17.5
Oven Dimensions	18"x20"x12"	20"x22"x14"	22"x24"x14"	24"x28"x14"
Oven Volume	4300	6100	7400	9400
Oven Factor	200	150	125	100
Weight Uncrated	500	600	750	900
U.S.S. gage, Body & Oven	18 & 14	16 & 14	16 & 12	14 & 12

Figs. 5 and 6. Rating and Capacity Schedules of Steel Ranges.

trally heated posts, but also at all other cantonments for small buildings of this type.

These small plants range in size from a few hundred sq. ft. of radiation up to more than 1,000 sq. ft. They are of the gravity circulating one-pipe system type, with boiler placed in a "lean-to" just outside, and on the low side of building so that all mains are, in

general, above the floor. Cast-iron sectional boilers are used, operating at from 2 to 5 lb. gauge pressure, and the condensation is returned to the boilers.

By the use of these systems it is possible to replace as many as 14 or 15 separately fired stoves with one boiler. The total number of cast-iron boilers installed for all heating purposes is about 1,700 and the radiation supplied by these is practically 3,000,000 sq. ft.

COOKING EQUIPMENT

The cooking requirement for 16 camps of 40,000 men each involved between 8,000 and 9,000 ranges and gave the Cantonment Division considerable anxiety. For a time it seemed that the only solution would be to install the ordinary field range (Fig. 5) on a raised hearth in each kitchen.

After numerous conferences with the National Association of Stove Manufacturers it was believed possible to produce the number and size of steel hotel type ranges required before Sept. 15, and bids were accordingly invited for steel hotel ranges as set forth in the following specifications:

GENERAL SPECIFICATIONS FOR RANGES

For one division there will be required approximately 500 hotel type steel ranges, varying in size from a range with approximately 950 square inches of top surface and approximately 4,300 cubic inches of oven volume, to a range with approximately 1,750 square inches of top surface and approximately 9,500 cubic inches of oven volume.

All ranges must be of heavy steel plate construction. All ranges must be furnished with waterbacks or waterfronts and without shelves at back or ends. Nickel-plated trimmings are not desired. Firebox linings must be of cast iron. All parts of ranges must be clean and free from rust. Entire outside of ranges must be painted with one coat of quick drying black japan.

Bidders must include in their proposals price for which they will furnish bake pans as specified. Bidders must furnish with their proposals all information called for in Proposal Data Sheet herewith.

Proposal Data for Steel Hotel Ranges:

1. Number of ranges bidders can supply on cars by (Sept. 1 and 15, 1917).*
2. Price, each, f. o. b. factory.
3. Price of bake pans as specified.
4. Size of cooking top, inches.
5. Width of oven, inches.
6. Depth of oven, inches.
7. Height of oven, inches.
8. Type of grate.
9. Size of firebox (inside of lining), length, width and depth, inches.
10. Waterback or waterfront.

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*Date to be inserted by the Purchasing Department.

11. Thickness of cooking top, inches.
12. Thickness of metal in body, U. S. S. Gauge.
13. Thickness of metal in oven, U. S. S. Gauge.
14. Weight of range set up, but not crated, pounds.
15. Size of smoke collar, diameter inches.
16. Castings, plain or malleable.

The question of rating the various ranges as to cooking capacity so that they could be apportioned intelligently, and so that comparisons could be made between different bids, was a most difficult problem.

How many men will a range cook for and what is the proper ratio between top cooking surface and oven volume? These and many similar factors were unknown. A careful study of the cantonment requirements finally showed that the cooking requirements could be classified as follows:

TABLE 4

NUMBER OF KITCHENS AND NUMBER OF MEN SERVED BY EACH

Not more than 20 men	21 to 40 men	41 to 75 men	76 to 123 men	124 to 200 men
1505	514	265	304	2895

A further investigation of service conditions showed that the No. 3 and No. 5 Army ranges would (in the hands of a good cook) take care of from an average of 20 (for the smaller) up to a maximum of 100 men (for the larger range). By reference to the dimension data of these ranges (See TABLE 5) it was possible to determine minimum top areas and oven volumes (See TABLE 6), and also factors giving areas and volumes per man, so that any range could be given a "man capacity" rating.

CLASSIFICATION SCHEDULE FOR SELECTION AND AWARD OF STEEL RANGES

In general, four sizes of ranges will be required for cantonment camps, of the capacities and specifications given in the following schedule. Single units which are multiples of any of these capacities will be considered and used if necessary. See note after Table 6.

(1) A 20 man range (Army No. 3).
(2) A 40 man range.
(3) A 60 man range.
(4) A 100 man range (Army No. 5).

TABLE 5

Capacity	20 Men	40 Men	60 Men	100 Men
Top Dimensions..	28"x34"	30"x42"	32"x48"	34"x52"
Top Area, sq. in...	950	1260	1560	1760
Oven Dimensions.	18"x20"x12"	20"x22"x14"	22"x24"x14"	24"x28"x14"
Oven Volume, cu. in.	4300	6100	7400	8400
Weight, uncrated, lbs.	500	600	750	900
No. Shelves.				
U. S. S. Ga. Body & Oven	18 & 14	16 & 14	16 & 12	14 & 12

STEEL COOKING RANGES—DETERMINATION OF UNIT CAPACITIES

Basis.—Ranges will be rated on the basis of capacity per man using oven volume in cubic inches and top surface area in square inches, as given in the following table. In all cases the ratio of total area of top surface to area of oven volume must be approximately 3 to 1, and never less than 2.60 to 1.00.

To find rating divide: (1) top area, and (2) oven volume, for ranges of the four sizes given, by the following factors, and take the average of the two results as representing the number of men range will serve.

TABLE 6

Class	Capacity Top Area			Oven Volume	
	Men	Factor	Std. Area	Factor	Std. Volume
(1)	20	45	950	200	4,300
			1,105		5,200
(2)	40	30	1,250	150	6,100
			1,410		6,750
(3)	60	25	1,560	125	7,400
			1,660		8,400
(4)	100	17.5	1,760	100	9,400

NOTE.—These ratings are based on single ranges. Set in battery ranges are more efficient per range.

Four class sizes were found desirable, as the ratio factors were much smaller for the larger sizes, and therefore each range had to be put in its approximate class before it could be rated. The writer is convinced now that the larger ranges were somewhat overrated in developing this table, and that for cantonment barrack service the No. 5, or large range, should have been placed at 80 men. As all ranges were classified on the same basis, however, the results were fairly comparable.

Each manufacturer was required to furnish and fit a set of bake pans to suit the oven of his individual range, as the standard army pans would fit very few of the commercial ranges.

The uncertainty of getting deliveries on the time specified was constantly kept in mind and plans were made to use the standard Army Field Range No. 1 in such quantities as might be necessary, and set it up as shown in Fig. 5. This range was used in the Reserve Officers' Training Camp kitchens quite generally this summer, and two of them will easily cook for a company of 200 men.

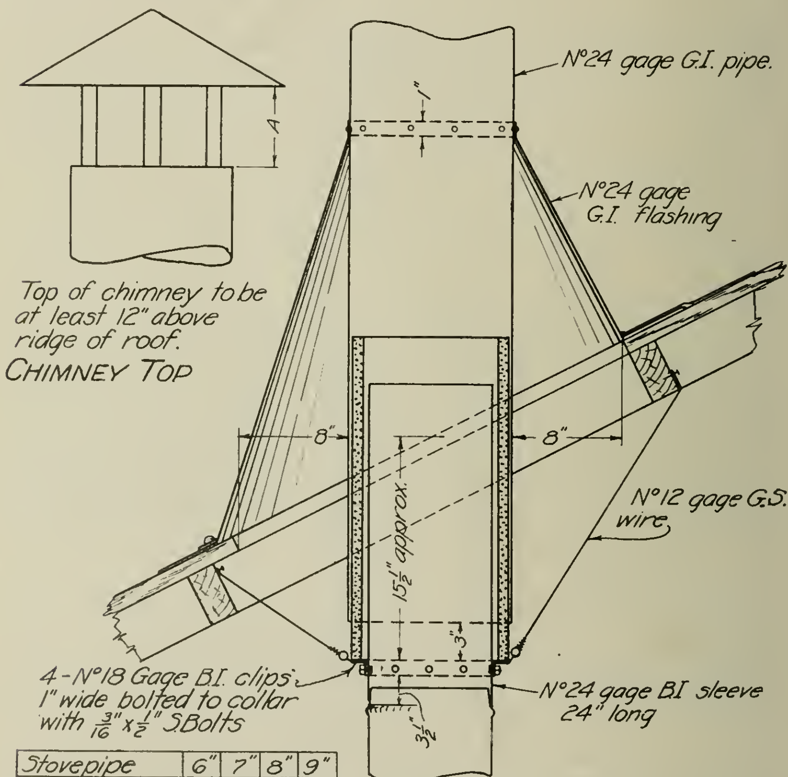
VALUE OF DUPLICATE STANDARD PATTERNS

The fact that sets of standard range patterns were not available for supplying manufacturers so that 3 or 4 standard ranges, all alike except in size, could have been furnished, delayed and complicated the production of this very important equipment enormously. The manufacturers showed every willingness to make any range, whether of their own line or not, for which duplicate sets of patterns and templates could be secured. Had large numbers of such duplicate

patterns been available standard ranges, such as are used in our permanent post equipment, could have been used throughout the cantonments.

SMOKE PIPE FLASHINGS

Several attempts were made to design a satisfactory smoke pipe flashing, which would support the exposed stack, act as an effective weather shield and reduce the fire hazard as far as possible. The problem was not so simple as its mere statement would indicate, and



Stovepipe	6"	7"	8"	9"
Sleeve	6"	7"	8"	9"
Flue lining	7"	8"	9"	10"
Gal. pipe	9"	10"	12"	12"
Dia. of cap	18"	20"	22"	22"
Dimension A	7"	8"	9"	9"

Fig. 7.

SMOKE PIPE DETAILS
CANTONMENT BUILDINGS

the fact that between 30,000 and 40,000 smoke pipes would be required to serve the various room heaters, cannon stoves, and ranges made the decision of vital importance. The arrangement shown in Fig. 7 was finally agreed upon, and separate detail sheets sent to all

cantonment quartermasters. The smoke pipes required nearly a million lineal feet of piping.

BAKERIES

In addition to the ranges each cantonment was equipped with bakeries having permanent ovens located in a special bakery building. In general, either three or four large brick ovens with a baking area of approximately 120 sq. ft. were installed. These ovens are operated 24 hours per day and have a capacity of from 15 to 20 tons of bread in that time. Since the army loaf weighs about 6 lbs., from 5,000 to 7,000 loaves of bread are produced daily, and the individual barrack kitchens are thereby relieved of a very heavy baking load.

LAUNDRY EQUIPMENT

The magnitude of the laundry requirements for the new army cantonments cannot be appreciated until a comparison is made between the equipment of a typical large commercial laundry and one of the new laundries. In fact, when this comparison was first drawn it seemed incredible that one cantonment required more equipment than existed in practically any of the largest laundries of the United States. The floor area needed was more than an acre per cantonment, the garment presses for the khaki uniforms numbered about 150 (ten times as many as the largest laundries contain), and the cost of building and equipment for a cantonment approached a quarter of a million dollars.

To provide complete laundry equipment at every camp with the funds available was, therefore, out of the question. As a result the War Department bought, under contract, enough machines to equip about six camps.

At the other ten camps various solutions of the washing problem were attempted. After many conferences, several laundry operators were induced to erect, at their own expense, complete laundries and place them within the cantonment reservation subject to government control and later acquirement at an agreed price. This scheme placed the responsibility for organizing a personnel and operating the laundry on the contractor, who in turn was practically guaranteed a minimum volume of business.

The determination of this minimum volume of business from a camp of 40,000 or more men, who were free to do with their laundry as they pleased since they pay for it individually, became a very fine problem in estimation. An average laundry bundle per man was scheduled and on an army price basis the gross receipts were calculated. In fact, innumerable and very conflicting data were collected from all kinds of camps and posts to establish the character of such an average bundle. This unit or typical bundle was also of prime importance in determining the equipment needed in government owned laundries.

The list finally made up included:

1 khaki uniform (presses)

1 suit underwear (tumblers)
1 O. D. shirt (tumblers)
2-3 pair socks (tumblers)
1 sheet (flat work ironer)
1 pillow case (flat work ironer)
¼ blanket (1 a month) (tumblers)
¼ mattress cover (1 a month) (tumblers)
3-4 handkerchiefs (flat work ironer)
2-3 towels (flat work ironer)

and on this unit bundle an estimate of the number of machines and floor space was based. For example, if the plant operates for two eight hour shifts 6 days a week, as was planned for the six government laundries, and we must handle 40,000 khaki uniforms a week, the rate of doing work determines the equipment. One girl or operator can operate two Universal presses and get off about 12 pieces per hour, which means six uniforms. This operator turns out 48 uniforms in 8 hours or 288 per week. For two shifts the output will be 576 per week keeping two presses going constantly, so that one press really handles 288 uniforms. Hence at least 140 presses are needed or 150 should be installed to allow for repairs and breakdowns. In this way, without going into more detail, the unit bundle could be used as a basis for determining the number of all classes of machines and the total floor area.

In drawing contracts with private parties the fact was not lost sight of, however, that the average enlisted man has seldom spent more than \$1.25 a month for his laundry service. Present day conditions will increase this monthly charge to \$1.50 or possibly \$1.75, which is the *most* that can be expected from the average soldier. Hence these private contracts provide: (1) for an appraisal value of plant based on original cost vouchers less depreciation, and, (2) a minimum monthly guarantee on volume of business of something less than $\$1.50 \times 40{,}000 = \$60{,}000$ per month per cantonment. Monthly variations are adjusted on the average for the term of the contracts which expire June 30, 1918. Thus, a deficit of \$10,000 in one month would be cancelled if an excess volume of business amounting to \$10,000 is done in some later month, and no payment would be made to the contractor.

In certain cases neither government owned and operated laundries or specially erected private contract laundries could be provided, and the commanding officer will have to arrange for as much of the laundry work to be done outside the reservation as can be handled by the local plants, and the balance will have to be taken care of as in the field—that is, each man may have to do his own washing until suitable plant facilities are available.

In conclusion, the reader must remember that the organization known as the Cantonment Division did not come into existence until after war was declared in April, 1917, and that much of the equipment for these 16 cantonments which now provide all facilities for the training, housing, feeding and sanitation of an army of half a

million men was not only not in existence but had not even been specified by July 1st of this year. In spite of this fact the Cantonment Division, together with its constructing quartermasters, in co-operation with the contractors and manufacturers of the country had practically completed the erection and equipment of these sixteen national army cantonments before October 1, 1917, and the garrisons had begun their military training.

DISCUSSION BY LETTER

Lieut. Col. H. S. Baker:* The construction of Camp Bowie, Fort Worth, Texas, presented no particular engineering difficulties. The site is high and naturally well drained. Abundant water supply and electricity for lighting were obtainable from the city and the Fort Worth Power & Light Company. Road material was at hand in sufficient quantities and the necessary capital was available to connect us with all these resources.

Like all National Guard Camps, the men are housed in tents, but for mess halls, storage, administration and other purposes, over 1,300 buildings were constructed, varying from temporary wooden shelters to permanent structures. The location of various units was thoroughly studied with a view to securing high, well drained ground for their camps. This results in a rather scattered camp, but while this may detract from its appearance it has numerous practical advantages. The open spaces between the camps of the various units afford drill grounds convenient of access and the separation of units provides the best possible fire stop.

A few features of engineering interest might be mentioned. The water system consists of approximately twelve miles of 6-inch steel pipe with screwed joints, laid about 24 inches deep. This pipe was laid by an experienced pipe line contractor who guaranteed that there would be no expansion troubles, as he could lay the pipe with sufficient slack in it to take up temporary changes. It is done by laying the pipe in a wavy line running from one side of the ditch to the other. While this method has been successful in most cases, it does not sufficiently provide for expansion where large connections and fixed points in the main are numerous. For this reason it has been necessary to install swing joints and expansion joints at several points. The water supply received from the City of Fort Worth is pumped through a booster station of two million gallons capacity, consisting of two 2-stage centrifugal pumps, motor driven. The station has given excellent service and was constructed and put in operation within a period of two weeks.

The construction work of this camp has been carried on smoothly and with harmony between all parties. This was due largely to the excellent quality of the Engineer and Quartermaster Officers who were sent to me as assistants, and the fact that the

*Constructing Quartermaster, Camp Bowie, Ft. Worth, Texas.

Contractor and all his force showed a disposition to push the work, hold down the cost, and co-operate in every way.

The Supervising Engineer, Mr. F. J. Von Zuben, City Engineer of Fort Worth, was of great assistance. He had charge of all engineering designs and layouts in connection with this work. The railroads co-operated under the direction of the American Railway Association, and gave remarkably good service in the transportation of materials. All government shipments were tagged and went through without delay. The local merchants and the Chamber of Commerce were helpful in a great many ways. In fact, they gave practically anything that was requested in the way of assistance.

This harmony was maintained with ease because we were fortunate in having exceptionally good men to deal with, both as assistants and contractors. Certain simple principles of organization were followed, however, which seemed to work very well. In the first place, the Cantonment Division of the Quartermaster Corps gave to the Constructing Quartermaster practically a free hand to build this camp. He is given typical plans and general instructions which tell him the results to be accomplished. A general contract is let which provides in broad terms that the contractor will do whatever work he is directed to do, and will be paid the cost of that work plus a certain fee. In brief, this is the carrying on of a public work on the assumption that both the Constructing Quartermaster and Contractor are honest and able. This, of course, is the usual assumption on which private business is conducted. Too often, however, public business is conducted on the contrary assumption that all men are dishonest unless their hands are tied, with the result that even with the best intentions they can accomplish very little. This principle was carried throughout the entire organization at Camp Bowie. The various classes of work were assigned to various officers. These officers had brief written instructions telling them definitely what their work was, including their responsibility and their authority. Within these limits they had a free hand. No orders were given at any time over their heads, and they responded to this confidence in a gratifying way.

When instructions were received from Washington concerning new work to be done, a full copy of all such instructions was transmitted to the officer in charge of that particular work, and through him the Contractor received also a full copy of all information received by the Constructing Quartermaster. In this way, everybody who had to do with the work had access to all information available concerning it. An effort was made at all times to allow no work to be held up for lack of decision on any question. Points were decided as fast as they came up, and if necessary referred to Washington with the statement that certain work had been done in emergency, and authority was requested to confirm it. This authority was freely granted whenever requested in this way.

A simple system of cost records was developed as soon as the work had gotten to a point where time could be taken for such re-

finements. In the first weeks of the work, while we were rushing to get the camp prepared to receive troops, our attention had to be devoted to organizing labor forces and to receiving material. As soon as this had been done and the work was running smoothly, simple systems of daily reports were instituted and separation of the work into distinct jobs, so that each morning the Constructing Quartermaster received a report for the work done the day before, showing the work accomplished under each heading, also the cost for the day and the total cost to date. When jobs were completed their cost were promptly summarized.

Little difficulty was experienced in dealing with mechanics and laborers. Mechanics in this part of Texas are quite thoroughly organized. As this is the normal condition in Chicago, it did not seem at all strange, and I found the men themselves and their leaders to be reasonable. When the work was started we ascertained the union wages which were paid in June, 1917, also union working conditions. These conditions and wages were maintained throughout our work. No effort was made to cut down these wages, and I believe the men felt that they were treated fairly at all times. They made no demand for increase in wages as a result of our necessity. In only one case was an increase granted, and this was a small class of men where it was found that the original scale was in error. The rate for teams was increased from $5 to $6 per day when it was found that we could not get teams at the lower rate. Aside from these few changes, no other changes were made in the wage scale during the course of the work, and no strikes occurred.

The men employed on the construction of the camp showed a patriotic spirit and I believe that most of them felt that they were doing their part in the war as much as the soldiers in the camp were.

In general, we tried to clearly define each man's duties; to relieve those in supervisory positions from details and to give authority and responsibility to the same men.

All engineering methods were left entirely to the Supervising Engineer. The Constructing Quartermaster did not attempt to act as engineer for this camp in any way. In the same way the road expert was allowed to handle his work in his own way.

THE RESISTANCE OF A GROUP OF PILES

By H. M. Westergaard*

Presented November 12th, 1917, Bridge and Structural Section.

1. *Scope of Paper.* The distribution of pressure among a group of vertical piles carrying a vertical load is often determined by considering the total horizontal cross-section of the group as the cross-section of a beam under similar loading. For this special case such a solution is satisfactory; but when some of the piles are battered and the group is irregular, like that shown in Fig. 1, the solution based on beam theory would be seriously in error. Exact analysis of the group in the figure gives the separate pressures indicated on each pile. It is noted that the maximum pressure coming on any pile in the group comes on one of the central piles, a result widely at variance with results of the solution mentioned above.**

It is proposed in this paper to present a method of determining the distribution of pressure among any irregular group of piles such as that shown in Fig. 1.

The piles are assumed to be arranged in planes parallel to the plane of the paper, and parallel to the resultant force, R. The displacements considered are parallel to this plane, and, in general, will be considered as infinitesimal. Each pile will be assumed to be hinged at its head and at some theoretical point near the lower end; thus, only axial loads will be considered as acting on the pile. The portion of the supported structure which rests immediately upon the piles will be called the "pier." It will be assumed to have the character of a solid mass, such that only small internal deformations will exist, when compared with the changes in length of the piles. The pier will be assumed to be supported by the piles only, both vertically and horizontally.

The pier and the piles taken together are assumed to constitute an elastic structure in which the displacement will, within certain limits, be proportional to the loads causing them. Such limits will in some cases proceed from the assumption that certain piles may not be designed to take tension. If, by applying the method which follows, any such pile is found to have tension the analysis is to be reapplied with this pile omitted, as though inactive in the structure.

The action of the structure under the load is defined when the motion of the pier is known. In the general case this motion may be characterized as a rotation of the pier through a certain angle about a certain center of rotation. In special cases the displacement of the pier is a parallel motion. Such a motion may be considered as a rotation about a point at infinity. We may in all cases, therefore,

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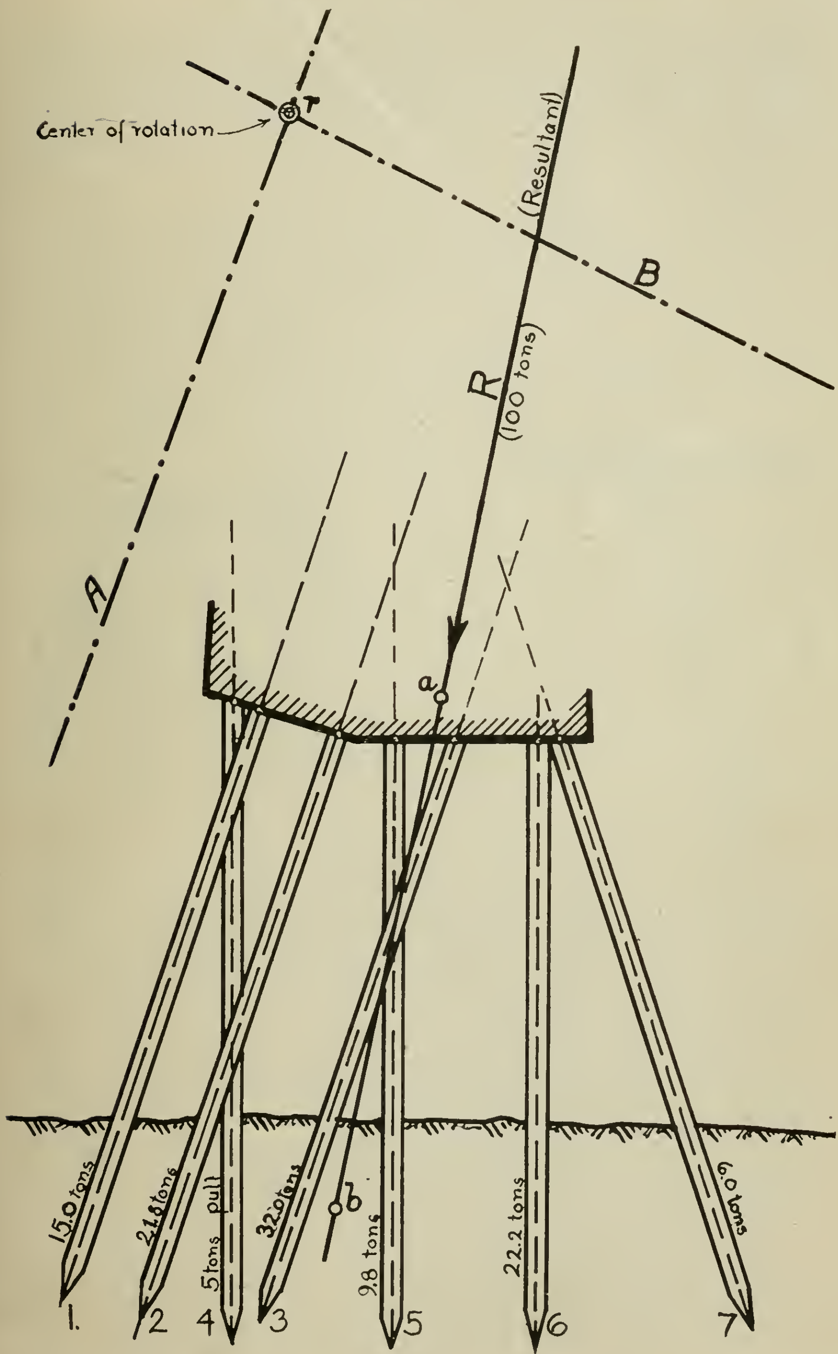
**A solution of the general case is proposed by Max Buchwald. See Deutsche Bauzeitung, Betonbeilage 1913, 2, p. 188, and 1915, 1, p. 77. This solution is incorrect as it does not take the deformations of the piles into consideration.



Center of rotation
r
A
B
(Resultant)
R
(100 tons)
a
b
15.0 tons
21.8 tons
5 tons pull
32.0 tons
9.8 tons
22.2 tons
6.0 tons
1.
2
4
3
5
6
7

Fig. 1

speak of a rotation as characterizing the displacement. It will first be shown how the pile pressures depend on the rotation center and rotation angle; then a lemma relating to certain qualities of reciprocity will be introduced. On this basis a method of dealing with

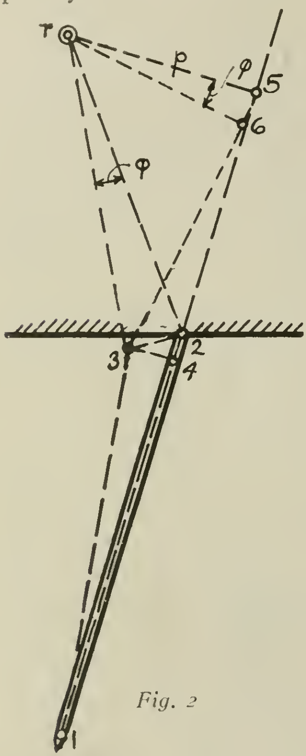


Fig. 2

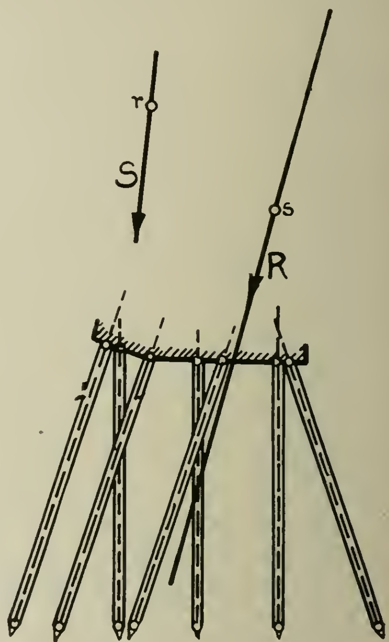


Fig. 3

any particular case will be developed. Finally the resistance in general will be discussed, assuming a varying resultant.

2. *To Find the Pile Pressures When Center of Rotation and Angle of Rotation Are Given.*—The notation used is as follows:

$r =$ center of rotation.

$\phi =$ angle of rotation measured in radians.

$p =$ distance from center line of any pile to center of rotation. p shall be considered positive if a shortening of the pile would increase ϕ, otherwise negative.

$l =$ length of pile measured from the assumed hinge at the top, to the theoretical point of support, (at which a hinge is assumed) near the lower end.

$e =$ shortening of pile.

$EA =$ modulus of elasticity times cross-section of pile.

$P =$ total pressure on any pile.

1-2 in Fig. 2 is the original position of a pile, and 2-3 the motion of the top end due to the rotation of the pile head through the angle

ϕ about r. 2-4 is the shortening e. Point 5 is the projection of the center of rotation on the center line of the pile. If point 5 is considered as attached to the pier it moves to the position 6. As the displacements are treated as infinitesimal quantities we may write: Distance 6-3 = 6-4, hence 2-4 $\doteq$ 5-6, or, the shortening of the pile is

$$e = p.\phi \tag{1}$$

(= distance of center line of pile from center of rotation times angle of rotation).

From formula (1) follows the expression for the corresponding pile pressure

$$P = p.(\phi EA/1) \tag{2}$$

3. *Reciprocity of Lines of Resultant and Centers of Rotation.*—If the resultant, R (Fig. 3), produces a rotation about a point r, then a resultant S passing through r will produce a rotation about some point s located on R. In other words, if R has its rotation center on S then S has its rotation center on R. This applies in general to the displacements of any line element attached to any elastic structure.

A proof of this theorem will now be presented. It follows closely one given by Ritter with his derivation of the fundamental qualities of the ellipse of elasticity.* It is based on the general theorem of reciprocity named after *Maxwell* and *Betti* §, which states in one form that the displacement along one path caused by a unit load along some other path is equal to the displacement along the second path due to a unit load along the first path. Applying this to the present case (Fig. 3) we have: the displacement of the point r in the direction S due to a unit load acting along R is equal to the displacement of the points on R in the direction R produced by a unit load acting along the line S. The displacement of r is zero when r is the center of rotation, hence the displacements of the points on R in the direction of R produced by the force S are zero. Hence the center of rotation s corresponding to a force along the line S is located on R, which was to be proved.

4. *To Find the Center of Rotation when the Resultant Force is given.*—The determination of the rotation center is the first step in the treatment of any particular case of loading. Let R in Fig. 1 be the resultant force transmitted through the pier to the group of piles. r is the corresponding center of rotation, which is to be determined. Now assume temporarily that the pier rotates through a certain angle about the point a chosen anywhere on the resultant R. This rotation would produce certain deformations in the piles. The corresponding pressures on the piles may be found by formula

*W. Ritter: Graphische Statik, III, Ed. 1900, p. 260.

§Given in most texts on Mechanics of Structures. Announced in its first special form by Maxwell (1864), later expanded by Betti (1872) and Lord Rayleigh (1873). For references and for a general proof see A. E. H. Love, Mathematical Theory of Elasticity, 1906, p. 170.

(2). These pressures are composed into the resultant A. By virtue of the above quality of reciprocity between lines of action and centers of rotation the center of rotation r will be located somewhere on A. We will then choose another point b on R, and find in the

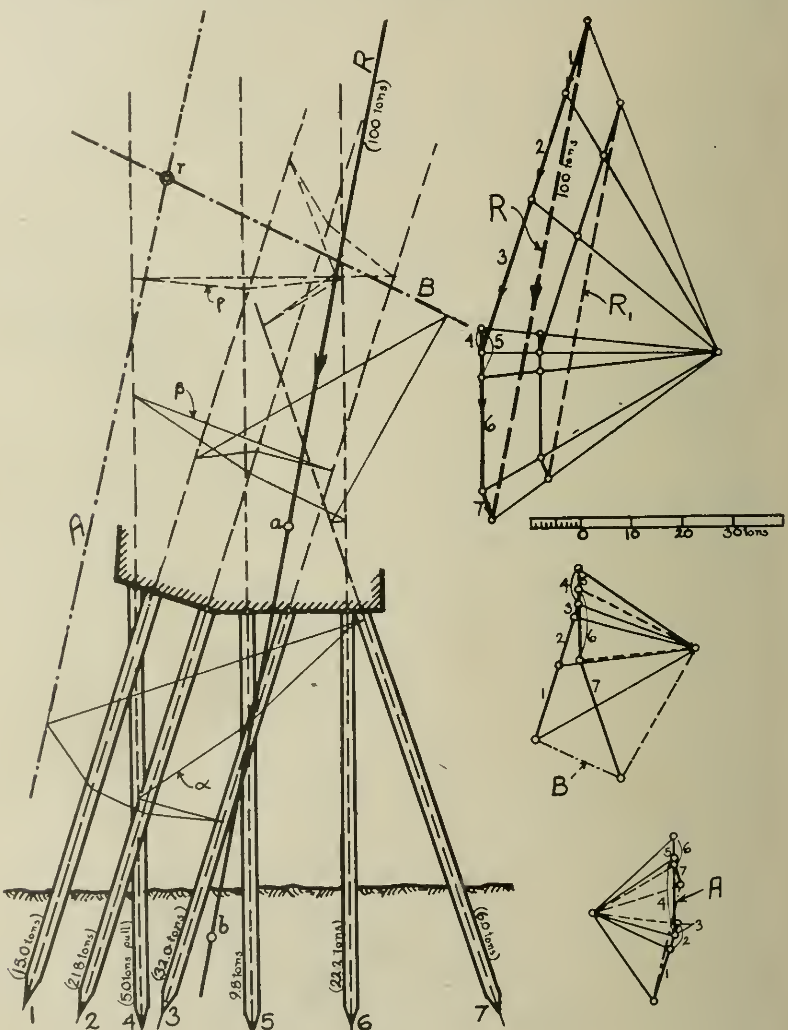


Fig. 4

same way its corresponding resultant B. The actual center of rotation r is the point of intersection of A and B.

In Fig. 4 the auxiliary resultants A and B are found by drawing the funicular polygons α and β. The corresponding force poly-

gons A and B are shown to the right in Fig. 4. The piles are in this case assumed to be of equal length, cross section, and modulus of elasticity. Then, owing to formula 2, the pressures used in the force polygons A and B may be measured as proportional to (for instance, half of) the distances from the respective centers of rotation to the center lines of the piles.

5. *To Find the Pile Pressures when the Resultant Force and the Center of Rotation are Known. Methods of Checking Results.*—Having determined the center of rotation r it will not be difficult to find the distribution of pile pressures. Assuming arbitrarily some angle of rotation ϕ_1 about the center of rotation r a set of corresponding pile pressures proportional to the real pressures may be found by formula 2. A force polygon gives the corresponding resultant R_1. In Fig. 4 the piles were assumed of equal length, cross section, and modulus of elasticity. Accordingly, the pile pressures in the force polygon R_1 are taken as proportional to (half of) the distance from r to the center lines of the piles. The force polygon for the real pile pressures is found in Fig. 4 by magnifying the force polygon R, in the ratio of R to R_1.

The results may be checked by the fact that R_1 found by the force polygon must have the same direction as the original resultant force R_1. A more complete check was obtained in Fig. 4 by drawing a funicular polygon ρ, corresponding to the force polygon R, and in this way the original line of action R was refound.

6. *Special Cases: Parallel Motion. Forces Applied Forming a Couple. Center of Elasticity.*—With special location of the force R, the lines A and B in Fig. 1 may become parallel. In that case the center of rotation would be at infinity and the motion of the pier would be a parallel motion perpendicular to the lines A and B. The shortenings or elongations of the piles due to parallel motions of the pier may be found graphically by the method shown in Fig. 5 (a, b, and c). Fig. 5a shows the group of piles and the pier under consideration. To find the effect of a unit horizontal motion of the pier lay out $\overline{\text{O-h}}$ = unity on a vertical line, as shown in Fig. 5b. Draw through O lines parallel to the piles 1, 2, 3, 4, 5 in Fig. 5a. A motion towards the left will shorten piles 1, 2, and 4, and elongate piles 3 and 5. The total shortenings and elongations of the piles are found as the distances in Fig. 5b from point h to the lines parallel to the piles. That this is correct will be seen by changing Fig. 2 in the following way: Move the rotation center r to infinity in vertical direction, make 2-3 horizontal and equal to unity, then 2-4 will continue to represent the shortening of the pile. By turning triangle 2-3-4 90° clockwise we reproduce the part of Fig. 5b which corresponds to one pile.

Pile shortenings due to a unit vertical parallel motion downwards are found in the same way in Fig. 5c. O-v is a horizontal vector equal to unity. The pile shortenings are equal to the distances

from the point v to the lines 1, 2 — 5 through point O parallel to the piles.

The shortenings of the piles determine the pressure on each pile by the usual formula (2). Each set of pile pressures may be composed into a resultant, for instance, by drawing a funicular polygon. In this way the resultants R_h and R_v in Fig. 5a were found; they correspond to the horizontal and vertical translations

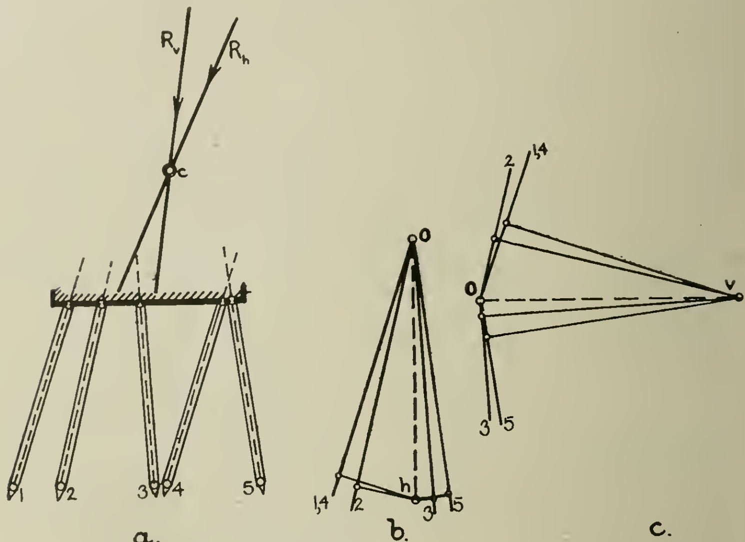


Fig. 5

respectively. Translations in other directions than the horizontal and vertical may be treated by the same method. In all cases resultants passing through c will be found.

Another important special case is that in which the resultant load is a couple. This case will appear to be closely related to that of a parallel motion; in fact, the two cases are in some respects reciprocal. Assume that the resultant is a couple; this may be interpreted as the limiting case in which the resultant force is at infinity. Then it is possible to apply the method illustrated in Fig. 1 and Fig. 4. We assume that R in Fig. 1 moves out to infinity. The two auxiliary centers of rotation a and b may be chosen as the points at infinity in the vertical and horizontal directions, respectively. The corresponding rotations are the parallel motions in horizontal and vertical directions, respectively. Assume that the group of piles under consideration is that shown in Fig. 5. Then the lines of action A and B corresponding to the rotations about a and b will be the same as R_h and R_v, the lines of the resultants producing horizontal and vertical translations. Their point of intersection c is the rotation center when the resultant is a couple. Instead of using the horizontal and vertical translations, any other two directions might

have been introduced in determining c. The relation between the moment of the couple and the corresponding angle of rotation is found by first determining the pile pressures for a certain angle of rotation, using the usual formula (2), and then composing these pressures into a couple.

It is evident that the point c is of particular importance in defining the general elastic qualities of the structures. It is the point through which the resultant must pass in order that a parallel motion shall take place, and it is the center of rotation when the resultant is a couple. Following the terminology used in Ritter's theory of the ellipse of elasticity it will be referred to as the *center of elasticity.* It is conjugated to the line of infinity as in Fig. 1, point r is to R, a to A, and b to B. It is also seen that the center of elasticity is essential in defining the interrelation between the cases of parallel motion and that in which the resultant is a couple.

7. *General Elastic Qualities of the Group of Piles.*—The elastic qualities of the group of piles as a whole may be described by the following characteristics:

The center of elasticity (c in Fig. 5a).

The resultant R_h corresponding to a unit horizontal translation (Fig. 5a).

The resultant R_v corresponding to a unit vertical translation.

The couple necessary to produce a unit rotation about the center of elasticity.

It is worth noting that R_h and R_v must be known both in magnitude and direction. Owing to Maxwell's and Betti's theorem of reciprocity, they are interrelated in that the vertical component of R_h is equal to the horizontal component of R_v.

The general state of elasticity of the group is defined by these data because any resulting load may be decomposed into components along R_h and R_v, and a couple. Each of these three component loads may be treated separately, as causing, respectively, a horizontal translation, a vertical translation, and a rotation about the center of elasticity.

Reference is made to three general methods of treating such cases of elastic resistance:

First, the method of the *ellipse of elasticity,* developed by *Ritter.** The center of the ellipse is the center of elasticity, and force and center of rotation correspond as anti-polar and anti-pole.

Secondly, the application of *Land's Stress Circle*§ should be mentioned. This method gives information about the elastic displacements of the center of elasticity due to resulting forces in

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*W. Ritter: Graphische Statik, for instance, Vol. III, Ed. 1900, pp. 259-264.

§Robert Land, Der Spannungskreis, etc., Zeitschrift des Vereines deutscher Ingenieure, 1895, pp. 1551-1554.

See also L. J. Johnson, The Determination of Unit Stresses in the General Case of Flexure, Association of Engineering Societies, Vol. 28, 1902, pp. 251-289.

varying direction. The method is convenient in graphical analysis.

Thirdly, attention is called to the use of a linear vector-equation (dyadics equation) in representing the relation between the displacement of the center of elasticity and the magnitude and direction of the force applied.*

Any of these three representations bring out the principal axes of the elastic resistance, that is, two directions perpendicular to one another, having the quality that forces in these directions produce motions of the center of elasticity in their own direction. The second method applying Land's circle, gives a convenient graphical determination of these principal axes.

8. *Classification of the Method Applied.*—If there are more than three rows of piles in the group the structure is statically indeterminate. It is treated by determining certain displacement qualities, say, two co-ordinates of the center of rotation, and the angle of rotation. In primarily determining displacements the method is contrasted with the great number of cases in which stresses in redundant members are the variables in the equations of elasticity, and it is classified with such methods as the slope-deflection method applying to frames.§ In our graphical treatment the two lines A and B in Fig. 1 intersecting one another in the center of rotation correspond to two of the necessary elasticity equations, while the solving of a third elasticity equation is replaced by the graphical determination of the magnitude of the resultant (Fig. 4, force polygons at right hand corner at top).

9. *General Conclusions.*—The greater the distance between the center of rotation and the center line of a certain pile, the greater is the load transmitted to that pile. This explains that in Fig. 4 the second and the third pile from the left carry greater pressures than the first pile. In general, it is seen that when the piles are not all parallel the greatest pressures are likely to occur in other than the extreme piles.

Figs. 6 and 7 show two designs of pile groups supporting, for instance, a bridge pier. In Fig. 6 all pile center lines intersect in one point c. A resultant load not passing through c cannot be resisted by the resultant of the pile pressures. Unless the pier or the piles are supported transversely such a resultant would cause an unrestrained rotation about c, and the pier would act as if it were hinged at c. The arrangement in Fig. 6 would not be adequate as an abutment support for a continuous arch system, neither would any arrangement in which the piles are approximately intersecting at one point.

Fig. 6 represents an extreme case. Now consider the design in Fig. 7. It is seen that a possible rotation about any point would be resisted by at least some of the pile pressures. In this respect the pile group in Fig. 7 possesses a superior rigidity compared with

*See for instance: L. Silberstein, Vectorial Mechanics, 1913, p. 92.

§Wilson-Maney, University of Illinois, Eng. Exp. Station, Bulletin No. 80, 1915.

that in Fig. 6. In general, to obtain rigidity and strength with a limited number of piles in a limited space two requirements must be satisfied: First, resistance against the various components of the resultant loads is to be secured by battering a proper number

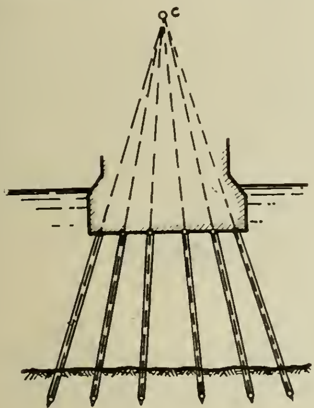

Fig. 6

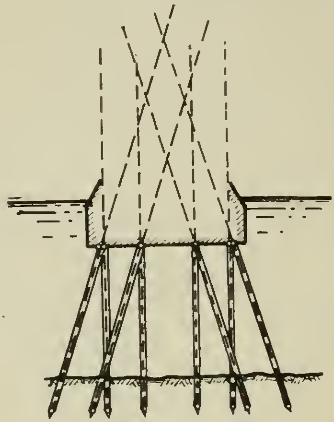

Fig. 7

of piles. Secondly, to prevent turning of the pier, points of intersection of center lines should be at proper distances from at least one other point of intersection of center lines of piles, and, if possible, the resultant load should pass between these points of intersection.

DISCUSSION

A Member: In figure 2 you assume a point of rotation; in the applied result of force and the result of two points applied there. Is either of those forces parallel to the original resultant force?

Professor Westergaard: No, there is no requirement. Another thing; if we have this center of rotation, we can always find the pressure on any pile just by taking the distance and multiplying that by a certain factor. That depends on the length entirely.

Mr. Dalstrom: I think we usually deal with vertical loads, except where we know that we have ground conditions where we have to devise some horizontal displacement. I think the paper of this evening is a valuable contribution to our knowledge of the subject in that we will probably turn to it and find the information when we want it analyzed.

Professor Westergaard: These particular piles were driven through soil, and for that reason one might assume that horizontal supports would be given in other ways than through the piles themselves.

The Chairman: Isn't it a fact, Professor, that the piles in one plane are more rare than in several planes?

Professor Westergaard: They don't have to be in one plane.

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings.

Meeting No. 985, December 3, 1917.

This was a regular meeting of the Society and was attended by ninety-five members and guests of the Society. The subject of the evening was "Cantonment Construction." Mr. C. B. Burdick, M. W. S. E., presented a paper describing the construction features of Camp Grant, including water supply and sewerage. Prof. N. B. Garver of the University of Illinois, presented a paper describing the organization, handling of materials and building erection at Camp Meade, Md. Prof. A. C. Willard of the University of Illinois, read a paper on the subject of heating, cooking and laundry equipment of cantonments. The subjects were discussed by Lieut.-Col. H. S. Baker by letter, giving a description of the construction of Camp Bowie, Fort Worth, Texas. Mr. S. A. Greeley added to the discussion with regard to the construction features of Camp Custer, Battle Creek, Michigan. The various papers gave a very comprehensive idea of the manner in which the engineering profession of the country responded to the necessity of erecting army cantonments under the stress of a short construction period.

The order of business of the meeting required the counting of the letter ballots on the amendments to the Constitution, as follows:

Article IV. Admissions. Amendment carried.
Article VI. Officers. Amendment carried.
Article VII. Nomination and Election of Officers:
- Amendment A. Providing for a Nominating Committee and Rotation of Names on the Ballot. Amendment carried.
- Amendment B. Providing for Rotation of Names on the Ballot. Amendment lost.

Article VIII. Duties of Officers and Committees. Amendment carried.
Article XI. Meetings. Amendment carried.
Article XIV. Miscellaneous. Amendment carried.

Meeting No. 986, December 10, 1917.

This was a general meeting of the Society and the ladies were invited. It was attended by 110 members and guests. The speaker of the evening was Mr. S. J. Duncan-Clark, War Analyst of the Chicago Evening Post, who spoke on the subject of "What the War News Means." This address gave a very complete synopsis of the logic of the news from the war front and the relation of the various activities which have been reported. A two reel moving picture entitled, "Over Here," was provided. This illustrated the construction of the cantonment at Fort Pike, Little Rock, Ark. The Entertainment Committee provided music for the evening.

Meeting No. 987, December 17, 1917.

This meeting was attended by eighty-five members and guests of the Society. The subject "What the War Means to the Engineer" was presented by Mr. Edward J. Mehren, vice-president and general manager of the McGraw-Hill Publishing Company, New York City. Mr. Mehren's study of the relation of the engineer to the war and the changes in the situation of the engineer due to the war, was very instructive and a prophecy of the large responsibility which the engineering profession will be called upon to assume.

Meeting No. 989, December 27, 1917.

This was a joint luncheon of the Electrical Section, W. S. E., and the Chicago Section, A. I. E. E., as guests of the Electric Club-Jovian League of Chicago. The meeting was attended by about 200. Major Robert A. Millikan, Vice-Chairman and Executive Office, National Research Council, prepared a paper on "The Relation of Science and Engineering to the War." In the absence of Major Millikan, Prof. Harvey B. Lemon of the University of Chicago presented the paper. This presented very clearly the resources of American science and patriotic service which members of scientic professions are making to the successful prosecution of the war.

At this meeting the report of the Nominating Committee of the Electrical Section was presented, placing in nomination the Executive Committee for the ensuing year.

EDGAR S. NETHERCUT, Secretary.